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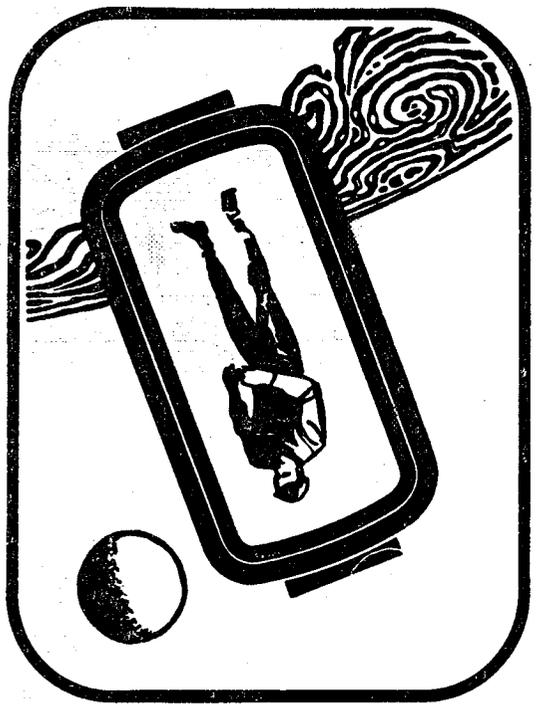
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PHASE B EXTENSION PERIOD EXECUTIVE SUMMARY
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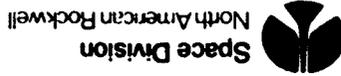


SD 71-214

MODULAR
space station
PHASE B EXTENSION
XTENSION PERIOD EXECUTIVE SUMMARY

CONTRACT NAS9-9953 MSC 02468
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EXTENSION PERIOD EXECUTIVE SUMMARY

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TECHNICAL REPORT INDEX/ABSTRACT

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<p>ABSTRACT</p> <p>THE EXECUTIVE SUMMARY PROVIDES A NARRATIVE SUMMARY OF TECHNICAL, PROGRAMMATIC, AND PLANNING INFORMATION DEVELOPED DURING THE SPACE STATION DEFINITION STUDY EXTENSION PERIOD. THE STUDY CONCENTRATED ON THE MODULAR SPACE STATION BUT ALSO INCLUDED TASKS PERTAINING TO SHUTTLE SORTIE MISSIONS AND INFORMATION MANAGEMENT ADVANCED DEVELOPMENT. IN ADDITION, A SERIES OF PROGRAM OPTIONS CONSIDERING TECHNICAL, SCHEDULE, AND PROGRAMMATIC ALTERNATIVES TO THE BASELINE PROGRAM WERE DEFINED AND EVALUATED.</p>
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FOREWORD

This document is one of a series required by Contract NAS9-9953, Exhibit C, Statement of Work for Phase B Extension-Modular Space Station Program Definition. It has been prepared by the Space Division, North American Rockwell Corporation, and is submitted to the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, in accordance with the requirements of Data Requirements List (DRL) MSC-T-575, Line Item 65.

Total documentation products of the extension period are listed in the following chart in categories that indicate their purpose and relationship to the program.

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS		STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C AND D	
				SPECIFICATIONS	PLANNING DATA
<p>EXTENSION PERIOD STUDY PLAN DRL-62 DRD MA-2071 SD 71-201</p>	<p>MSS PRELIMINARY SYSTEM DESIGN DRL-68 DRD SE-3711 SD 71-217</p>	<p>MSS DRAWINGS DRL-67 DRD SE-3701 SD 71-216</p>	<p>EXTENSION PERIOD EXECUTIVE SUMMARY DRL-65 DRD MA-012 SD 71-214</p>	<p>MSS PRELIMINARY PERFORMANCE SPECIFICATIONS DRL-66 DRD SE-3691 SD 71-215</p>	<p>MSS PROGRAM MASTER PLAN DRL-76 DRD MA-2091 SD 71-225</p>
<p>QUARTERLY PROGRESS REPORTS DRL-64 DRD MA-2081 SD 71-213, -235, -576</p>	<p>MSS MASS PROPERTIES DRL-69 DRD SE-3721 SD 71-218, -219</p>	<p>MSS MOCKUP REVIEW AND EVALUATION DRL-70 DRD SE-3731 SD 71-220</p>			<p>MSS PROGRAM COST AND SCHEDULE ESTIMATES DRL-77 DRD MA-013(REV. A) SD 71-226</p>
<p>FINANCIAL MANAGEMENT REPORTS DRL-63 DRD MF-004</p>	<p>MSS INTEGRATED GROUND OPERATIONS DRL-73 DRD SE-3761 SD 71-222</p>	<p>MSS KSC LAUNCH SITE SUPPORT DEFINITION DRL-61 DRD AI-0051 SD 71-211</p>			<p>MSS PROGRAM OPERATIONS PLAN DRL-74 DRD SE-3771 SD 71-273</p>
	<p>MSS SHUTTLE INTERFACE REQUIREMENTS DRL-71 DRD SE-3741 SD 71-221</p>	<p>INFORMATION MANAGEMENT ADVANCED DEVELOPMENT DRL-72 DRD SE-3751 SD 71-211</p>			
	<p>MSS SAFETY ANALYSIS DRL-75 DRD SA-0321 SD 71-224</p>				

The documentation for the original Phase B contract is listed in the following chart.

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS	STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C & D	
			SPECIFICATIONS	PLANNING DATA
PHASE B DEFINITION STUDY PLAN DRL 1 DRD MA 009 SD 70-009	SPACE STATION DEFINITION DOCUMENT DRL 9 DRD SE 023 SD 70-186	EXECUTIVE SUMMARY REPORT DRL 3 DRD MA 012 SD 70-181	SPACE STATION DEVELOPMENT DEFINITION DOCUMENT DRL 18 DRD MA 018A	
PROGRAM REVIEW MONTHLY DRL 2 DRD MA 010	CREW FACILITIES DEFINITION DOCUMENT DRL 10 DRD SE 026 SD 70-187	SPACE BASE & PLANNING DATA SCHEDULE DATA DRL 23 DRD MA 018 SD 70-187	PART A ELEMENT PLAN SD 70-180-2	
PROGRAM REVIEW REPORT DRL 3 DRD MA 011	INITIAL LOGISTICS SYSTEM CONCEPT DOCUMENT DRL 15 DRD SE 024 SD 70-181	ADVANCED LOGISTICS SYSTEM CONCEPT DRL 16 DRD SE 031 SD 70-182	PHASES C & D PRELIMINARY SPECIFICATIONS DRL 4 DRD MA 014 SD 70-126 THROUGH SD 70-141	
PROGRAM REVIEW REPORT DRL 3 DRD MA 011	PLANETARY MISSION CONCEPT DOCUMENT DRL 20 DRD MA 016 SD 70-188	SUMMARY OF SPECIAL ELEMENTS DRL 25 DRD MA 019 SD 70-08-011	PHASES C & D DATA REQUIREMENTS DRL 7 DRD MA 017 SD 70-188	
FINANCIAL COST REPORT DRL 7 DRD MF 004	PRELIMINARY SYSTEMS DESIGN SHEETS DRL 11 DRD SE 024	MASS PROPERTIES DRL 13 DRD SE 027 SD 70-183		

Similarly, the documentation for the options period is given in the following chart.

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS	STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C & D	
			SPECIFICATIONS	PLANNING DATA
OPTIONS PERIOD STUDY PLAN DRL 36 DRD MA 184	NUCLEAR REACTOR POWERED SPACE STATION DEFINITION DOCUMENT DRL 34 DRD MA 181 SD 70-030	OPTIONS PERIOD EXECUTIVE SUMMARY DRL 35 DRD MA 184 SD 70-037	NUCLEAR REACTOR-POWERED SPACE STATION DEVELOPMENT DEFINITION DRL 31	
QUARTERLY REVIEW DRL 48 DRD MA 182	NUCLEAR REACTOR POWERED SPACE STATION DESIGN SHEETS DRL 38 DRD MA 181 SD 70-030		PART A ELEMENT PROGRAM MASTER PLAN SD 70-005-7	
FINANCIAL COST REPORT DRL 38 DRD MF 7211	NUCLEAR POWER REACTOR POWERED SPACE STATION DESIGN SHEETS DRL 37 DRD SE 1917 SD 70-043		NUCLEAR REACTOR-POWERED SPACE STATION PRELIMINARY PERFORMANCE DRL 32 DRD SE 1987 SD 70-032	
	SHUTTLE LAUNCHED SPACE STATION DESIGN SHEETS DRL 39 DRD MA 181 SD 70-046		INTERNATIONAL SYSTEM OF UNITS CONVERSION DRL 31 DRD MF 0227 SD 70-043	
	CARGO MODULE DEFINITION DESIGN SHEETS DRL 40 DRD SE 1927 SD 70-038			
	SPACE STATION DESIGN SHEETS DRL 41 DRD SE 1917 SD 70-041			
	SPACE STATION DESIGN SHEETS DRL 42 DRD SE 1927 SD 70-042			
	SPACE STATION DESIGN SHEETS DRL 43 DRD SE 1917 SD 70-044			
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INTRODUCTION

This Executive Summary covers the space station extension period study performed by North American Rockwell Corporation (NR) and major subcontractors starting in February, 1970. The extension period is the third phase of the NASA space station study. In the original study, a large-diameter space station was designed; options to that contract were implemented in which a number of design alternatives were studied including the conceptual definition of a modular space station. The extension period was then negotiated to conduct the preliminary design of a modular space station.

The initial phase of the study was based on the space station being the precursor program to a much larger space base. Beyond the space base, manned planetary missions were projected to the mid-1980's and both the space station and base contributed technology, systems, and modules to these missions. The space station itself was planned to be operational as early as 1975 and would be launched on a Saturn V-class booster.

The space station configuration resulting from the basic study was 33 feet in diameter and contained four decks plus two toroidal ends and a power/artificial gravity boom. It supported a crew of 12 and could support a full complement of experiments and space applications activities. This integral space station was configured so that an artificial gravity by rotation could be assessed using the spent S-II stage as a counterweight.

At the conclusion of the integral station design study, concepts of a modular space station that required only the space shuttle for initial launch and logistics supply were introduced. Many configuration classes were studied with the result that the open class, characterized by a central core with end-docked modules, was selected. This configuration (as it evolved from the many iterations in the design process) is shown in Figures 1 and 2. Figure 1 shows the initial space station, which is capable of supporting six crew members and a large complement of experiments. Figure 2 shows the growth space station that is fully equivalent to the integral station mentioned previously.

The space station shown is distinguished by several features in deference to the primary drivers of the program; safety, cost, and utility to the station user in research and applications endeavors. Safety is assured by many things: absence of hazards, redundancy of critical equipment, a forgiving design. Beyond this, the station is effectively two stations in one, with dual habitable volumes, subsystem redundancy divided between these

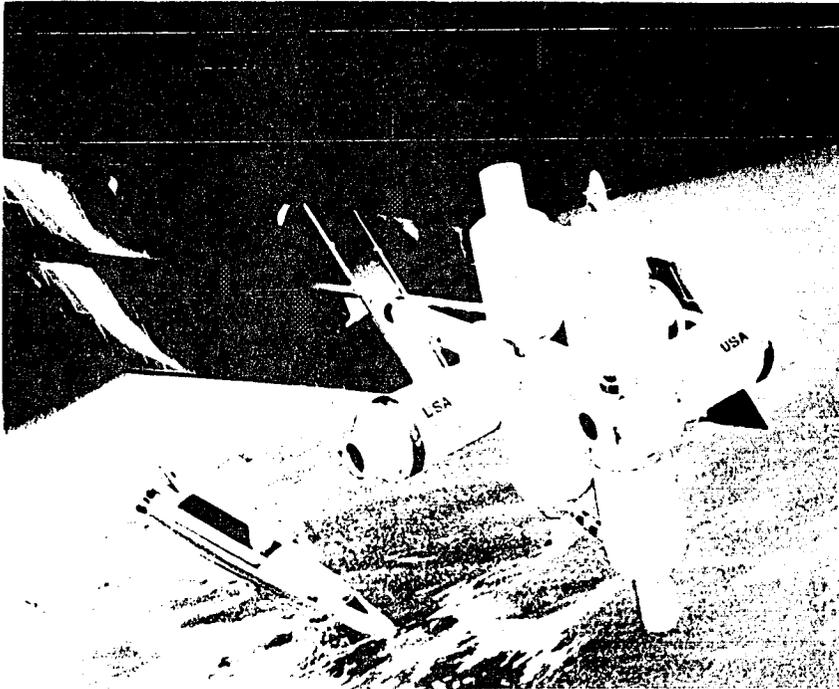


Figure 1. Initial Station

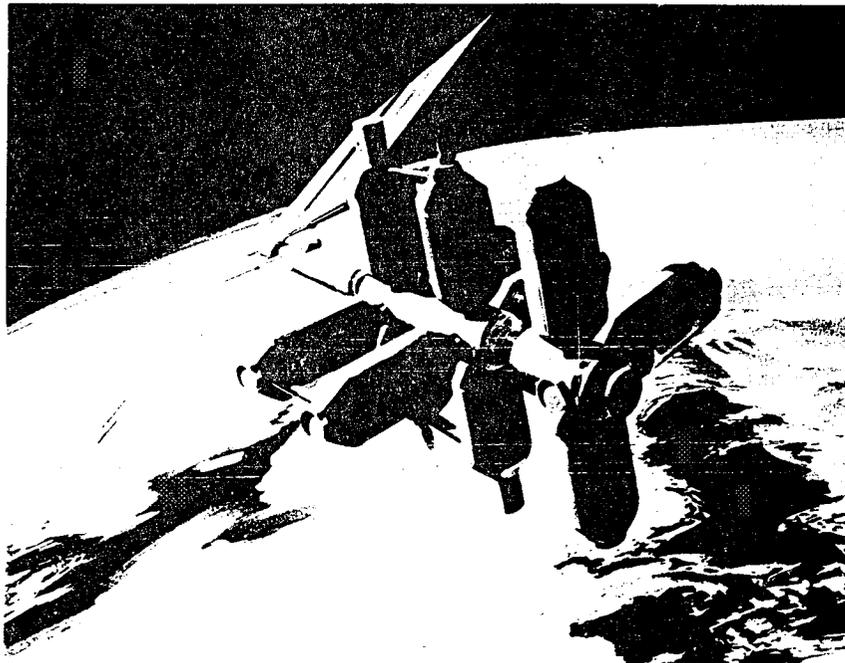


Figure 2. Growth Station



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volumes, and dual shirtsleeve egress from any normally inhabited module to the other volume. Crew safety and mission continuation are assured despite any credible series of mishaps.

Costs, particularly early funding requirements, are reduced by minimum requirements for new developments, a development and operations approach that takes advantage of the shuttle's capability, and module commonality whereby all normally inhabited station modules are repeats of one structural design and two basic interior arrangements.

Analyses of space station user requirements were a primary source of station design requirements. Two areas were particularly influential, a requirement to inhibit all venting, engine firing, etc., for up to 12 hours, and a decision to normally fly the station with its geometric axes fixed relative to the earth and relative to the orbit plane.

This report is concerned primarily with the design and operation of the initial space station, since that was the primary thrust of the study. The report also covers the growth space station and several important ancillary activities. These include a shuttle sortie mission and design analysis, a reduced shuttle payload size impact assessment, a series of alternative program options, a mockup evaluation, and a series of advanced development tasks concerning the information management subsystem.



MODULAR SPACE STATION

This section contains the results of analysis and design activities on the modular space station. The first five sections describe the initial (6 man) space station; the growth (12 man) space station deltas are described in the sixth section, and the programmatic (cost and schedule) discussed in the last section.

REQUIREMENTS

The modular space station study began with a comprehensive set of requirements developed during the preceding study of the integral station. These were set down as the guidelines and constraints (MSC-03696) that governed the study. The primary requirement was to provide an on-orbit capability to support a variety of experiments and space applications as defined in the NASA 1971 Blue Book. The fully configured station would contain a general-purpose laboratory and be capable of supporting two research and applications modules (RAM's).

Primary emphasis was to minimize peak annual funding requirements in addition to minimizing program funding up to the achievement of initial operational capability (IOC). In the accomplishment of these program cost requirements, commonality was established as a primary consideration. In addition, the adoption of a development approach that provides the basis for the reduction of the number and cost of test articles and major tests was required.

The facility would consist of modules that could be carried to orbit within the shuttle cargo bay and assembled on orbit. It must be capable of independent operations with a full crew for 120 days, although shuttle support launches can be programmed as often as one every 30 days. The station atmosphere would be 14.7 psia oxygen/nitrogen and would maintain CO₂ partial pressure below 3.0 mmHg.

Mission

The experiment disciplines to be operated in the modular space station (MSS) were examined to establish a mission flight envelope. The result, shown in Figure 3, ranges in altitude from 240 nautical miles to 270 nautical miles at an orbit inclination of 55 degrees.

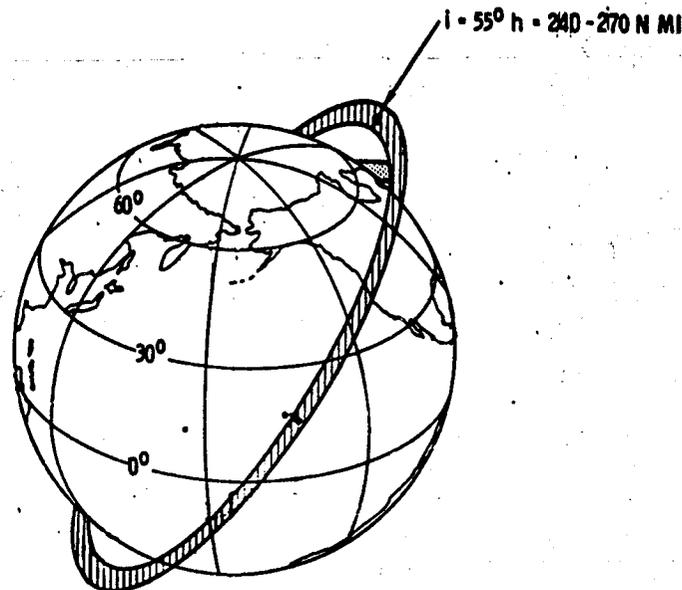


Figure 3. Modular Space Station Flight Envelope

An evaluation of subsystem performance and logistic resupply requirements resulted in a selected subsystem design-to altitude of 240 nautical miles. This provides the capability of operating within established consumable resupply frequencies at the worst case.

An evaluation of the subsystem performance requirements and the space station consumable requirements resulted in the selection of a design-to altitude of 240 nautical miles. The selection of this design-to altitude permitted the space station to operate anywhere within the mission flight envelope in the shuttle launch frequency constraints with the worst case logistics support requirements.

An operational altitude of 270 nautical miles was selected as the baseline primarily because of earth-viewing experiment considerations. This altitude results in approximately daily repeatable ground tracks permitting observations of the same ground sites on multiple successive days. By operating slightly off a repeatable ground track altitude, total earth coverage is achieved over a period of several days.

Experiments

The primary source of experiment definition data was NASA document NHB7150.1, preliminary Edition of Reference Earth Orbital Research and



Applications Investigations (Blue Book). In the Blue Book, experiments related by common objectives or requirements are grouped into functional program elements (FPE's).

The initial space station must be capable of supporting selected, partial, modified, or combined FPE's from the Blue Book. The growth space station must have the capability to accommodate all Blue Book FPE's, but not simultaneously.

The two major outputs of MSS experiment requirements analyses were the definition of evolving experiment laboratories and their requirements, and the definition of general-purpose laboratory (GPL) requirements for the initial MSS. From these were produced the Reference Experiment Program (REP). The REP definition resulted from analysis of alternative time phasings of experiments which considered different experiment sequences, support capability requirements, and costs.

Since the MSS evolves in capability from the six-man initial station to the growth station, a parallel evolution was defined for experiment requirements. In NR's approach, MSS laboratories were defined that progressively increased in capability through two or more discrete levels. In general, one laboratory was defined for each FPE. By definition, the highest level (level III) is the complete FPE where all Blue Book-defined equipment is available and all Blue Book-defined experiments can be performed.

In general, the lowest level (level I) was defined to be compatible with the capabilities of shuttle sortie missions; level II, with the initial MSS; and level III, with the growth MSS. From the total set of typical experiments defined in the Blue Book, subsets were selected that are consistent with the subsets of experiment objectives. Integrated support requirements were then defined for each laboratory at each implementation level, based on the requirements of the typical experiments assigned to the laboratory at that level.

The laboratory definitions and key support requirement ranges by level are shown in Figure 4. Also shown in the figure is the median value for each parameter. Laboratory definitions are presented in terms of the range of the number of experiments and the range of the number of experiment equipment items selected per laboratory at each level. Note that level III includes the complete Blue Book complement. Following these, the range of experiment equipment weight at each laboratory level is displayed. Finally, ranges for three key support requirements are shown for each laboratory at each level, namely (1) the electrical energy input required every 24 hours (in kilowatt hours), (2) the total digital data output each 24 hours (in bits), and (3) the level of crew support required to conduct the laboratory research and applications investigations (in man-hours per 24-hour day).

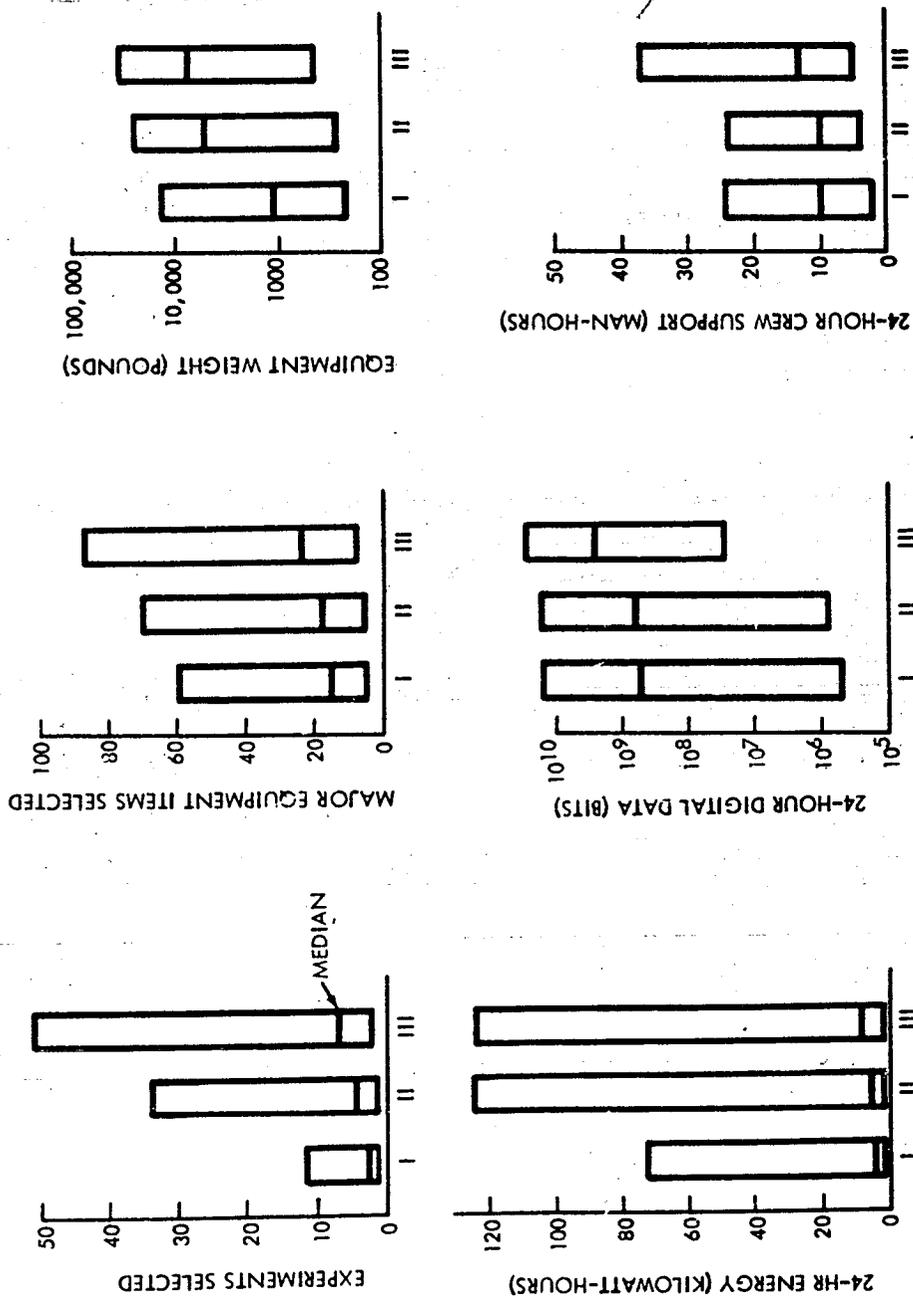


Figure 4. Laboratory Definition and Support Requirements Summary
(Range by Level with Median Shown)



Since the Initial MSS could not accommodate all of the level II laboratories in its five-year existence, priorities for laboratory implementation were defined. These were based on the nature of the accomplishments of each laboratory (benefit category) and on the intrinsic value of the laboratory (worth rating) in satisfying important disciplinary goals in a program of balanced socio-economic benefit and scientific return.

The desired balanced program requires a proper mixture of socio-economic and scientific benefits. The hierarchy of laboratories selected to produce the desired mixture emphasizes worth, both in application and scientific experiments. High-worth category 1 (socio-economic benefits) experiments were placed in a higher rank than high-worth category 2 (scientific knowledge) experiments. The rationale for this choice is based on the assumption that the momentum upon which the MSS program will depend for the development of its full potential (in all benefit areas) will come from socio-economic benefits derived early in the program. Laboratory requirements priorities and MSS resources were then used to prepare the reference experiment program.

Integral with the station is a general-purpose laboratory. The GPL is a facility containing equipment that performs a variety of functions common to the level II laboratories. It also provides utilities and operating volume for the accommodation of all level II laboratories not assigned to RAM's. General-purpose laboratory requirements are dependent upon the laboratory evolution philosophy and the reference experiment program, since requirements for the GPL were defined specifically to support level II laboratories accommodated during the initial MSS time period.

Twenty-five functional requirements were identified for the initial station GPL. These resulted in the identification of 54 equipment items weighing a total of 3300 pounds, which must be provided as part of the GPL. In addition, volume and utilities must be provided to accommodate the equipment required to perform 59 additional functions.

The GPL is required to provide celestial and earth-viewing capability (including telescopic observation of ground targets); utilities; mechanical, electrical/electronic, and optical maintenance; biomedical functions; data analysis capability; photographic processing; physical science functions; deployment of equipment to the space environment; and volume for the accommodation of investigator-provided equipment.

In addition to the GPL, the station supports two RAM's either attached to a docking port or free flyers controlled and serviced from the station.

System Safety

System safety requirements become a prominent generator of system-level space station requirements because they are concerned with the safety of personnel as well as with safety of the vehicle. These requirements drive both the configuration and subsystem designs.

The system safety goal that follows was imposed at the outset as a top-level study ground rule:

"As a goal, no single malfunction or credible combination of malfunctions and/or accidents shall result in serious injury to personnel or in crew abandonment of the space station."

This goal suggests the methodology for assuring the goal is met, i. e., identify credible malfunctions and accidents and provide design and operational features to prevent personnel injury or abandonment of the station. The approach used by NR was to establish models for credible malfunctions and accidents and to derive general system safety criteria from these. The criteria were used in developing requirements and preliminary designs; and the preliminary designs were analyzed to determine possible hazards and additional safety requirements.

Some of the specific design and operational requirements that resulted from the application of the criteria are described in the following paragraphs.

Compartmentation

If an accident occurs that results in depressurization, atmospheric contamination, or loss of some critical function, the crew must survive safely in a separate pressurized area until the affected volume can be restored to a habitable condition or until they are rescued by the shuttle.

The design solution adopted by NR consists of arranging the habitable modules into two pressure-isolatable volumes of approximately equal capabilities. Each of the two volumes contains its own environmental control, thermal control, and information subsystems; a control center; docking capability; and emergency supplies. Each can support the crew of six indefinitely (subject to adequate consumables) independently of the other volume. Primary electrical power is supplied to both volumes from a common power module that will be available to both volumes even if one has been evacuated.

Dual Egress

To satisfy the system goal, it was necessary to provide for two or more ways in and out of each habitable volume, located and separated from each other so that a single accident will not prevent access to both of them. This, therefore, led to a criterion of two or more entry/exit paths including IVA/EVA.

Failure Tolerance Criteria

The failure tolerance criteria became a major driver in establishing subsystem configurations. These were redefined and clarified to relate the criteria to critical functions on a complete station basis. The failure tolerance criteria were further redefined for the buildup period (prior to manning the station) on the basis of capability to perform successful shuttle docking to the portion of the station in orbit and boarding the station shirt-sleeve or IVA.

The failure tolerance criteria established during the Phase B Study are provided in Table 1.

Table 1. Failure Tolerance Criteria

Failures	Manned	Buildup (Unmanned)
1	Nominal performance	Nominal performance (capable of being manned shirtsleeve or IVA)
2	Reduced capability	Reduced performance (capable of being manned shirtsleeve or IVA at least 96 hours)
3	Emergency—96 hours (crew removal) abandon station	Abandon station

BUILDUP AND OPERATION

The most important difference between the modular space station and the integral space station is the on-orbit buildup of station modules into an operational system. This requirement was the source of major complexity



differences, and strongly influenced the selection, design, and placement of subsystem assemblies. Once fully configured on-orbit, the station operation and features were similar to the integral station with very little compromise caused by modularity.

Buildup Analysis and Selection

All modules will be manufactured, checked out, and launched with complete subsystems. This approach results in a design that minimizes the impact on station activation for normal subsystem operations.

With all subsystems installed at launch, the internal connections made, and fluid lines filled, on-orbit assembly operations are reduced primarily to module-to-module interface connections, verification, and checkout. Other startup operations such as subsystem filling, purging, and recheck are eliminated.

The initial module to be delivered to orbit preferably has a minimum amount of spare equipment over and above that required for normal operations. The NR analyses have shown that this objective was best achieved with the core module launched first, followed by the power module. These two assembled modules are flown in a gravity gradient mode at minimum (nearly quiescent) power between buildup launches. The assembly and buildup approach has been organized to allow only minimum system activation until permanent manning occurs. Only subsystems required to maintain the station in a quiescent mode between launches are activated. Some subsystems are deactivated during quiescent operations (e.g., the reaction control subsystem, most of the ECLS subsystem except for atmosphere and thermal control, and lighting). Redundant wakeup receivers provide the communications link from ground or shuttle to the station. These receivers have the capability of interrogating subsystem status, turning quiescent systems on and off, and commanding attitude orientation and control.

A subsequent launch adds the crew/control module. The solar arrays are then partially deployed and operated automatically with the now-present information subsystem (ISS). The configuration is now flown oriented about the principal axis, and water electrolysis supplies the reactants for secondary power from the fuel cells and for the RCS engines. In subsequent sequences, shown in Figure 5, the first laboratory/ECLSS module and the second crew/control module are added at 30-day launch intervals.

With the addition of a cargo module and the six-man crew, the configuration has reached its initial operational capability (IOC).

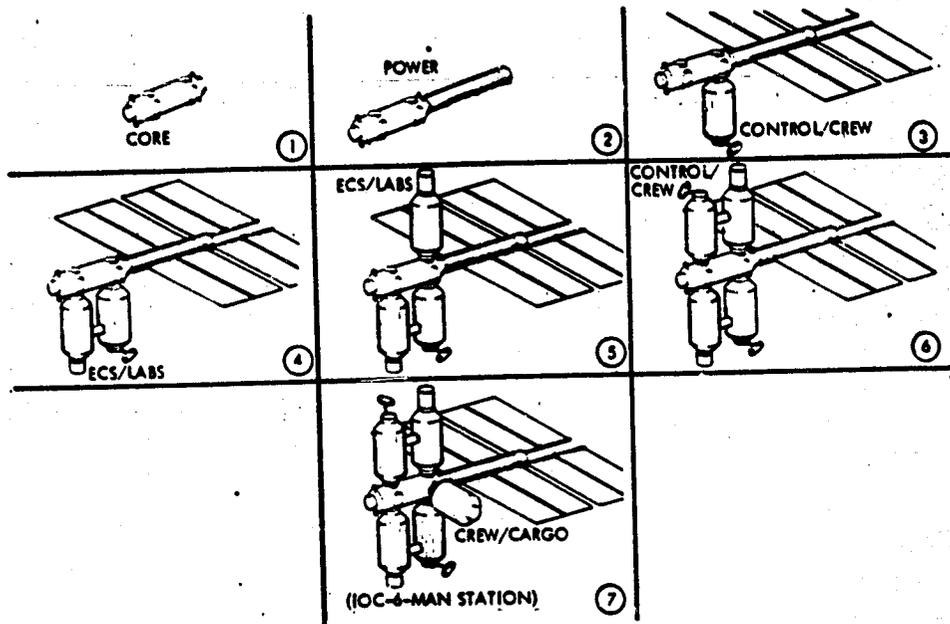


Figure 5. MSS Buildup Sequence (Initial Station)

Flight Mode

The modular space station is capable of maintaining a local vertical hold and an inertial hold flight mode. This provides the basic stable platform mode for earth viewing and solar/stellar viewing instruments, respectively. The reference flight mode orientation is illustrated in Figure 6. The X-axis is perpendicular to the orbit plane; the Z axis is along the local vertical (down); and the Y axis is opposite the velocity vector. The flight mode acronym, therefore, is XPOP, ZLV, YOVV. This mode will be flown at all times except for the short periods of inertial flight for solar and stellar viewing and shuttle approach and berthing/unberthing operations.

The XPOP flight mode is selected based on minimizing solar array shadowing by the station modules, best in-plane ground viewing, best orientation for combined orbit makeup, and control moment gyro desaturation.

Mission Sequence Plan

The final mission sequence plan is summarized in Figure 7, which presents the experiment time phasing, accommodation mode, crew requirements, and logistics requirements. The disciplines are presented in the

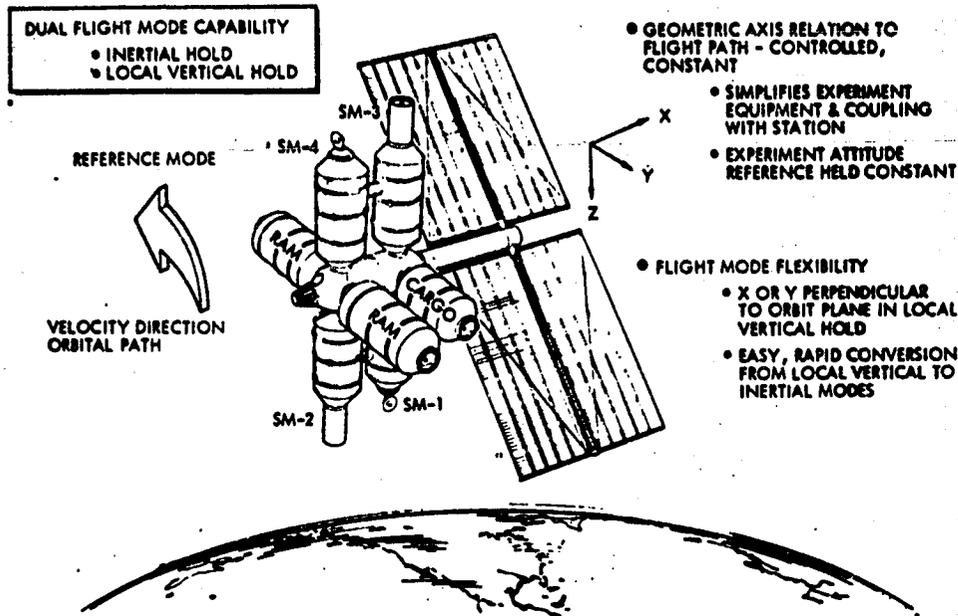


Figure 6. MSS Flight Mode

order in which the FPE's are introduced into the program.

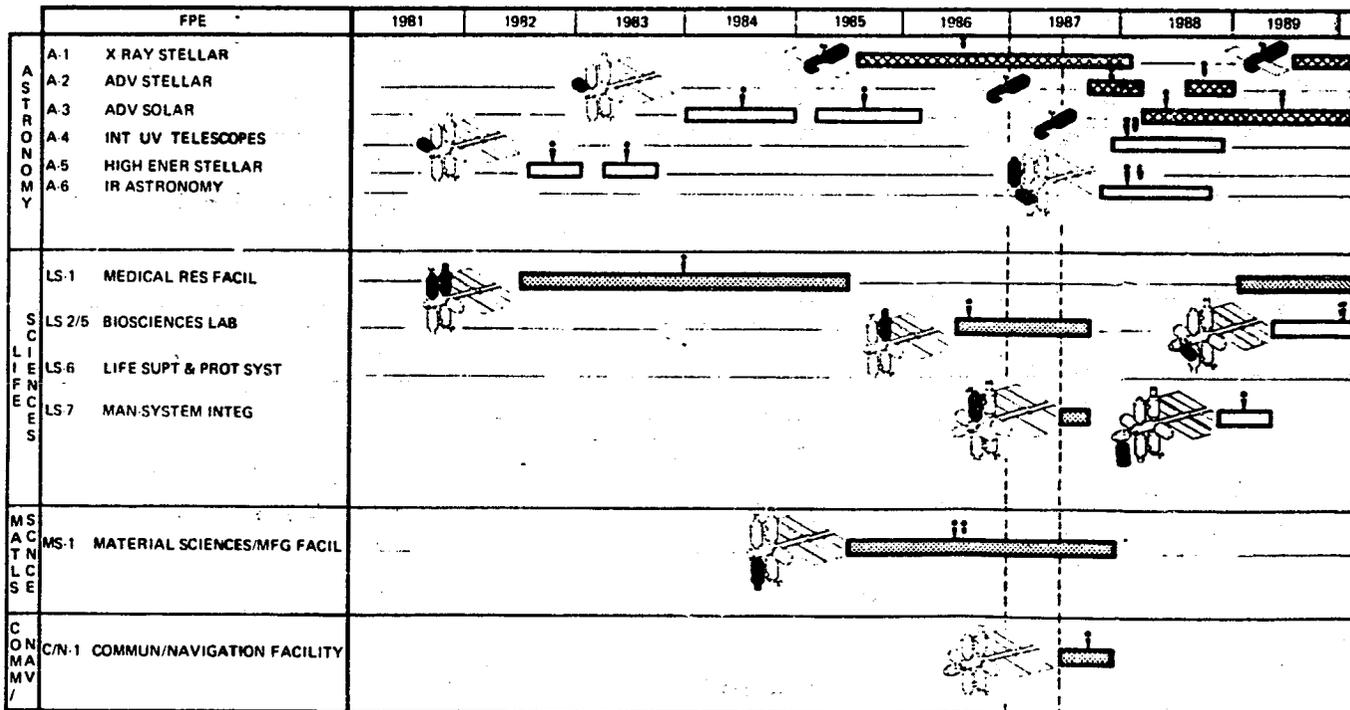
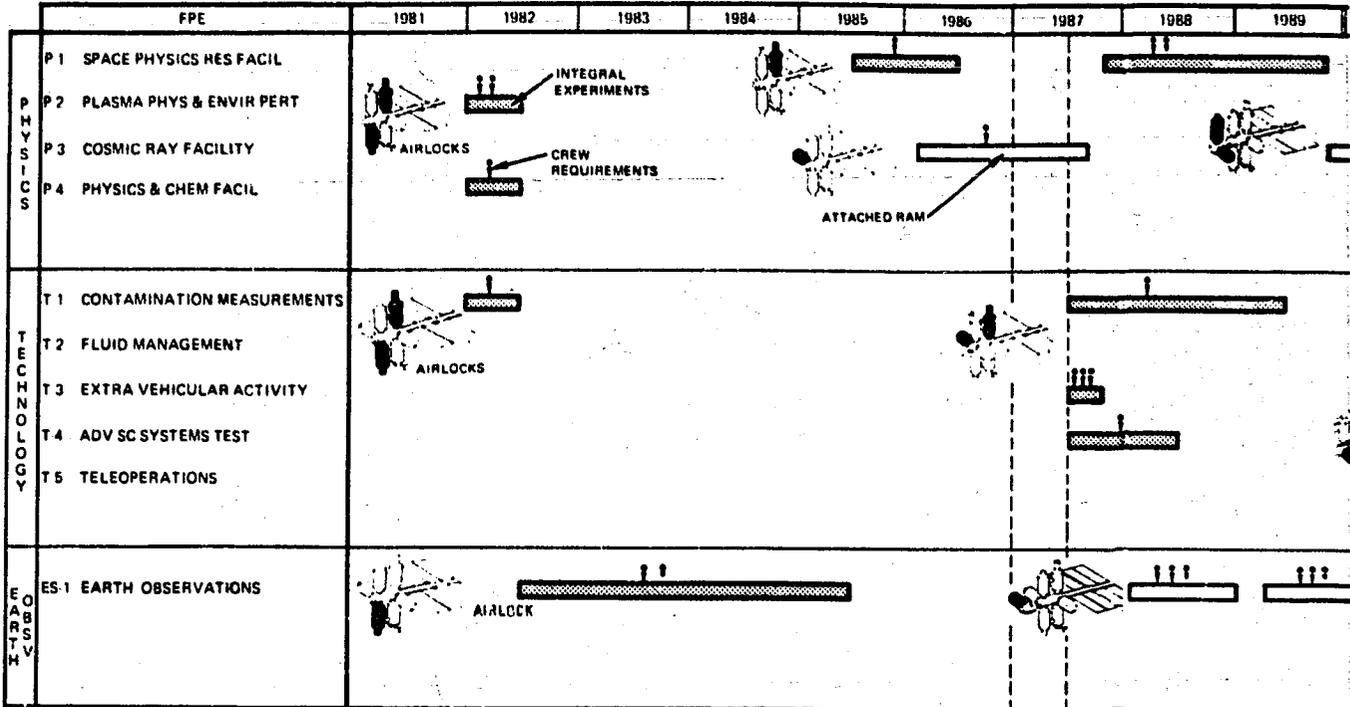
The mission sequence plan was developed assuming each FPE is operated for one cycle at each level of activity (level II and level III). In this manner, each FPE is accommodated by the program at the earliest possible date. The resultant total program, including buildup to the initial space station and buildup to the growth space station, requires approximately 16 years to complete.

The mission sequence plan and the associated experiment scheduling is intended to be representative of the operations of the modular space station. It is not intended to represent the only experiment program that can be scheduled because the space station has the inherent capability and flexibility to accommodate alternative programs.

Crew Requirements

The crew requirements for station operations and experiment-support operations for the initial space station are on the order of 25 man-hours per day. These operations include the routine daily operations of the space station, routine and periodic maintenance, housekeeping, monitoring and control of detached RAM's, etc. The experiment operations are those associated with the daily conduct of the space station experiments. Based on 25 man-hours per day for station operations and experiment support operations and a 10-hour work day, approximately 35 man-hours per day are available for experiment operations for the initial space station.

FOLDOUT FRAME



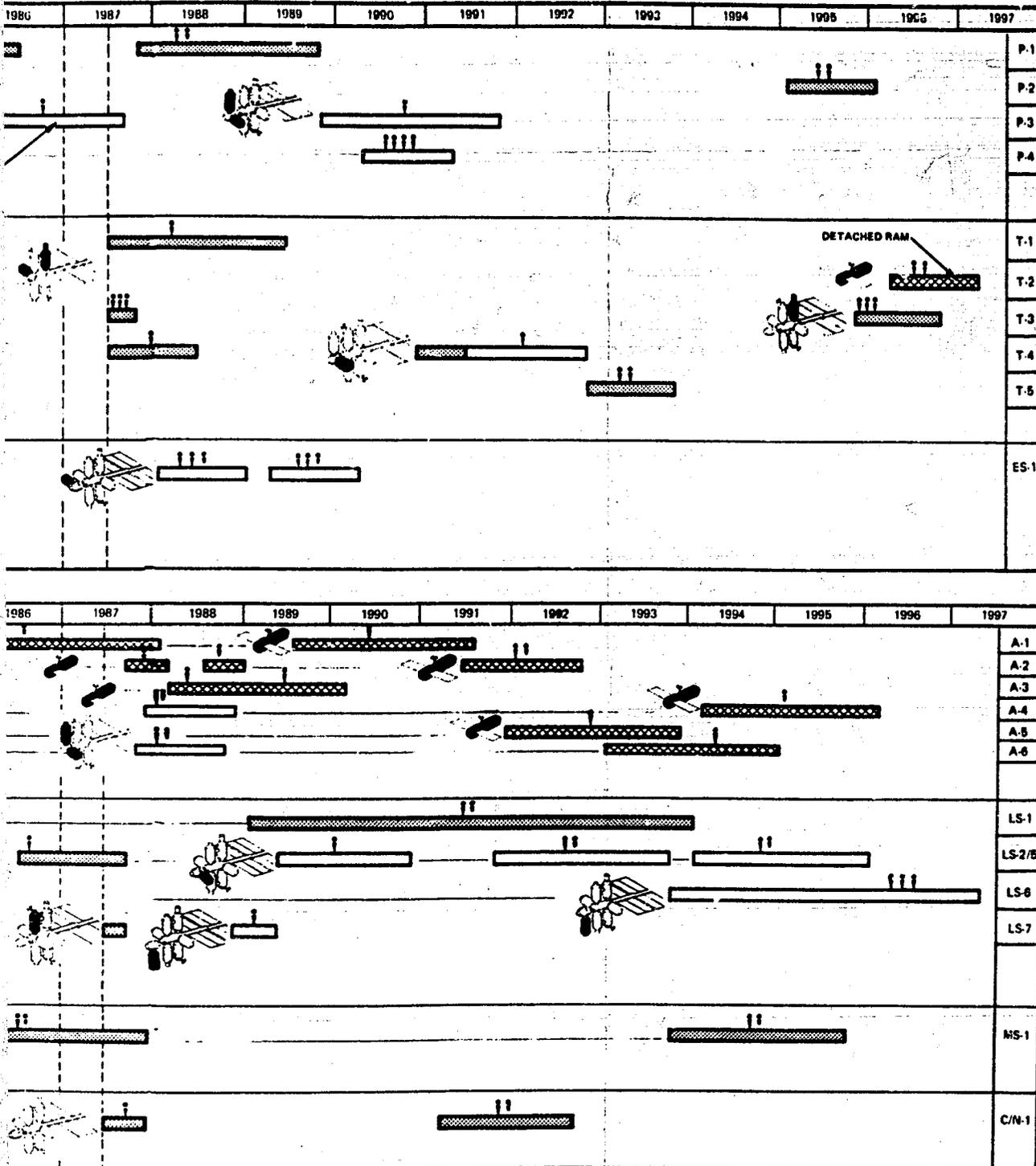


Figure 7. Mission Sequence Plan



Twenty-seven crew skills identified are necessary for the conduct of the experiment operations. The phasing of the skill requirements, based on the mission sequence plan, results in a variation in the number of skills required at any one time throughout the program.

Logistics Requirements

The total logistics requirements to support space station operations and the experiment program previously defined are listed in Table 2. Approximately 1900 pounds per month are required for basic operations of the initial space station and 3600 pounds per month are required for the growth space station. Based on the experiment scheduling identified previously, approximately 1000 pounds per month are required for operations of the initial space station experiments and 1800 pounds per month for the growth space station. The experiment logistics requirements shown are an average value of the requirements for consumables and experiment equipment which must be delivered during the operation of the space station. An additional logistics requirement is imposed by the need for emergency oxygen and nitrogen for emergency operations. This has been included at the bottom of Table 2.

Shuttle Support Requirements

The shuttle launch frequency (shown in Figure 8) for delivery of crew and cargo is dictated primarily by considerations of crew rotation because these missions occur at a frequency that permits the concurrent delivery of the cargo necessary for support of the station and experiment operations. The logistics capability for crew and cargo delivery is based on a cargo module capacity of approximately 11,800 pounds per flight for shuttle missions which concurrently deliver up to six crewmen.

In addition to the shuttle missions required for delivery of the station modules and for the crew and cargo delivery, shuttle missions are required for the delivery of RAM's and the support sections necessary for the operation of detached RAM's. For the experiment program identified previously, only two support sections are required to support detached RAM operations, with a third unit provided for backup purposes. These support sections are periodically returned to earth for refurbishment and redelivered to orbit for further use.

Table 2. Logistics Resupply Requirements

Logistics Item	Resupply Requirement (lb 30 days)	
	Initial Station	Growth Station
Clothing	78	152
Linens	62	124
Grooming	10	20
Medical	15	30
Utensils	56	112
Food	650	1300
Gaseous storage - O ₂	3	3
- N ₂	247	377
Water	369	716
Special life support LiOH	10	10
Water management	40	81
Atmospheric control	217	434
CO ₂ management	57	113
Waste management	27	53
Hygiene	11	21
Spares	34	69
Subtotal	1884	3615
Average experiment resupply	1000	1800
Total 30-day average	2884	5415
Up-down emergency (90 hr) O ₂	404	633
H ₂	23	36
Total emergency	427	600

Manipulator/Docking

The selection of the concept for the delivery and controlled mating of space station modules has an impact on the space station design requirements. The two basic mating alternatives considered (see Figure 9) were berthing using an MSS or shuttle manipulator and direct docking. In the berthing concept, the station or shuttle manipulator is used to perform all mating operations between the space station, space station modules, and the

SHUTTLE TRANSPORT MISSIONS	YEAR																
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
STATION MODULES	[Timeline showing station modules from 1981 to 1997]																
CREW/CARGO	[Timeline showing crew/cargo from 1981 to 1997]																
CARGO	[Timeline showing cargo from 1981 to 1997]																
RAMS	[Timeline showing RAMS from 1981 to 1997]																
SUPPORT SECTIONS	[Timeline showing support sections from 1981 to 1997]																

	CARGO MODULE CAPABILITY
	• ~ 11,800 LB/FLIGHT
	CARGO REQUIREMENTS *
	• INITIAL STATION - 2884 LB/MO
	• GROWTH STATION - 5415 LB/MO
	EXCLUDES UP-DOWN EMERGENCY CARGO

	SHUTTLE SUPPORT SUMMARY
INITIAL STATION	
• STATION MODULES	6
• CREW/CARGO	20
• RAMS	9
• SUPPORT SECTIONS	1
	36 FLIGHTS (~1/8 WEEKS)
GROWTH STATION:	
• STATION MODULES	4
• CREW & CARGO	54
• RAMS	29
• SUPPORT SECTIONS	12
	99 FLIGHTS (~1/6 WEEKS)

Figure 8. Shuttle Support Requirements

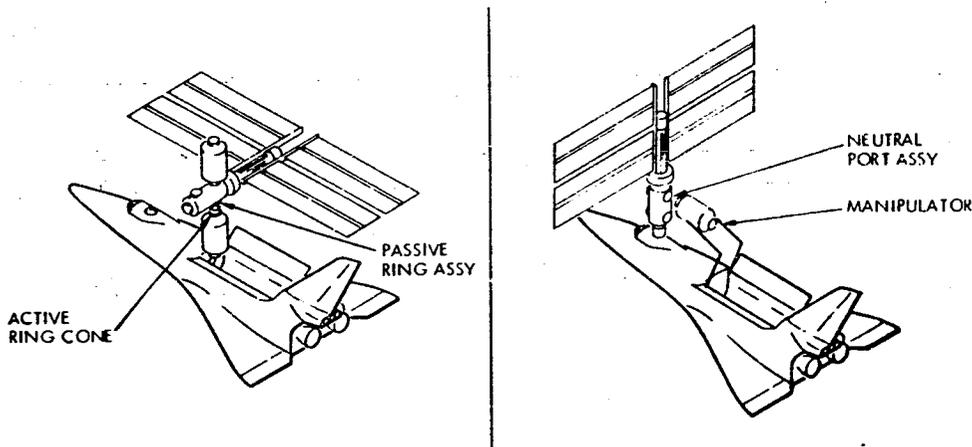


Figure 9. Berthing and Docking Concepts

space shuttle. The manipulator assures that relative velocities are small so that no attenuation is required. Early studies showed that the shuttle manipulator could perform all berthing operations and therefore the manipulator on the station was deleted from further analyses. In the direct docking concept, space shuttle maneuvering is utilized to perform the mating operations. The differences in the requirements for berthing and docking were analyzed to assess the impact of deferring the berthing versus docking selection.

Berthing or docking alignment errors are the key drivers which establish module spacing. Module manufacturing and docked alignment errors are minor compared to attitude stability and alignment (angular and displacement) errors. Figure 10 illustrates the expected error values for berthing and docking. The berthing data shown are based on a shuttle berthed to the core module. Direct docking of a module requires more module displacement than direct docking the shuttle only (see lower right hand graph in Figure 10). Therefore, this case is illustrated.

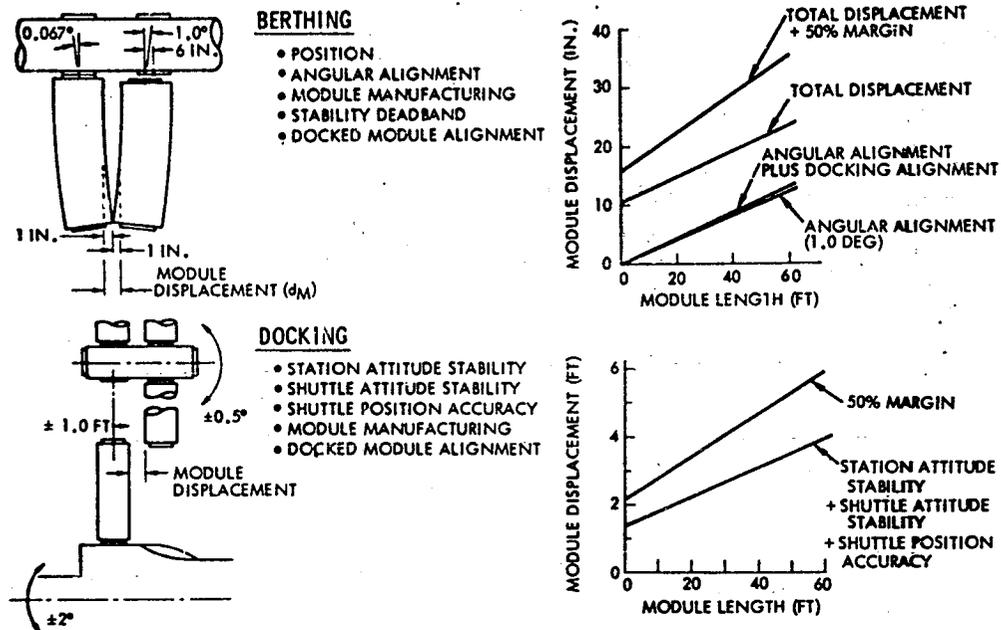


Figure 10. Alignment Errors

With a 50-percent displacement margin and 40-foot-long modules, module spacing on the core should be about 30 inches for berthing and 60 inches for direct docking.

The principal considerations that impact the berthing/docking selection are listed in Table 3. If the direct docking mode is adopted, the resultant module spacing will accommodate either the berthing or the

docking mode. Direct docking has the advantage of being independent of manipulator reach. However, adapters may be required for modules of unequal length. The core module must be approximately 3 feet longer to accommodate direct docking and the common modules must all have active docking ports with energy-absorbing attenuation because of higher relative velocities.

Table 3. Mode Selection Considerations Summary

Considerations	Impact of Mode Selection	
	Berthing	Docking
Change in mode	Not possible	Will accommodate either
Manipulation design	Reach dependent	Independent
Core module penalty	None	3-foot length
Common module penalty	None	Active ports with attenuation
Shuttle adapter	Sized to shuttle requirements	Sized to module length deltas

Based on the mode selection considerations identified previously, the manipulator berthing mode was retained as the baseline mode, but the space station design was made compatible with direct docking by providing a 5-foot nominal clearance between modules with a resultant core module weight penalty of approximately 384 pounds. This decision allows final selection of the berthing versus docking mode to be deferred until Phase C design studies when increased knowledge of manipulator operations should be available.

MAINTENANCE APPROACH

With the modular space station, the capability exists to return major components, up to and including complete modules, to earth. To exploit this unique capability, a study was performed to examine the maintenance issues and to establish the requirements that would be imposed on the crew and system-level operations for both on-orbit and ground maintenance.

To assess the impact of replacing modules as the primary maintenance approach, the time relationship for station buildup as a function of shuttle launches was established. Using the maximum shuttle flight frequency of one flight per month, any requirement to return a module for maintenance

seriously impacts the buildup schedule.

To minimize module returns, the module mean time between failure (MTBF) must be sufficiently high to ensure that the probability of adequate shuttle launches (P_s) could be achieved without any operational impact.

Table 4 illustrates that with a $P_s = 90$ percent, the module MTBF would range from 2.4 to 5 years. For a module, MTBF's of these magnitudes become very difficult to achieve without extremely high levels of active/standby redundancy at the subassembly and component levels. From this analysis, it was concluded that the returnable module approach must be limited for the following reasons:

1. High module MTBF required during initial station buildup to preclude exceeding available shuttle launches.
2. High module MTBF's require high MTBF's at the subassembly and component levels.
3. More installed spares are required and this in-place redundancy adds complexity.
4. Ground and on-orbit checkout complexity increases because of added redundancy.

An alternative approach is an extension of the approach used for Station A, i. e., designing all units for in-flight replacement. While previous data have shown that this is the desired direction, there are three areas where difficult design solutions make this approach questionable. These are the design of major structural assemblies (seals, primary structures), complex or location-constrained assemblies (insulation panels, external radiators), and equipment that is hazardous to remove or replace.

Table 4. Module MTBF for P_s of 50 and 90 Percent

Mission Phase	Number of Replaceable Modules	Number of Available Launches	Module MTBF's	
			$P_s = 50\%$	$P_s = 90\%$
Initial buildup	5	1	1.8 (yr)	5 (yr)
Normal operations	5	8	1.5 (yr)	2.4 (yr)
Growth buildup	8	4	2.6 (yr)	5 (yr)
Normal operations (nominal resupply)	8	6	2.2 (yr)	3.6 (yr)

P_s = probability of adequate shuttle launches for module replacements

In addition to the difficulty of design, there is the high probability of EVA being required to support some maintenance activities. The analysis concluded that the system be designed for on-orbit maintenance (Approach B) with a capability also provided for module return as an unscheduled event. Specific design criteria were established to satisfy these requirements.

As assessment of initial station in-flight replaceable units (IFRU), failure rates, and scheduled maintenance revealed that approximately 175 man-hours per month are required for maintenance activities. With the availability of 720 man-hours per month of unscheduled crew personal time, uncertainties in the maintenance estimate could vary by as much as a factor of 5 without impacting scheduled crew activities.

Ground Operations

Ground operations in support of the launch and buildup of the modular space station start early in the development program. Ground rules established for the prelaunch and refurbishment activities are:

1. Modules will be individually checked out using an integration tool to provide the integration functions.
2. Combined tests of those modules required to accomplish the basic station functions of multiple berthing, secondary power generation, and energy storage and subsystem control will be conducted before launch of the initial module.
3. The information subsystem onboard checkout capability will provide the primary prelaunch checkout functions.

To be cost-effective, the MSS development program is designed to make multiple use of test articles (modules) for development purposes. After test, these modules are converted into tools for the checkout of flight modules at the manufacturing site and at the launch site, as well as supporting the continuing mission. Figure 11 summarizes the major hardware utilization and flow.

The compatibility assessment vehicle (CAV) is the primary fixture for physical and functional integration of the space station subsystems and their associated software at the manufacturing site. This is the first point in the ground operations program that functional, fully configured subsystems and flight-type structures are brought together. The CAV configuration will utilize prototype subsystems permitting an early start on the complex integration tasks. A subsequent update to flight-type subsystems will convert the CAV to an acceptance fixture.

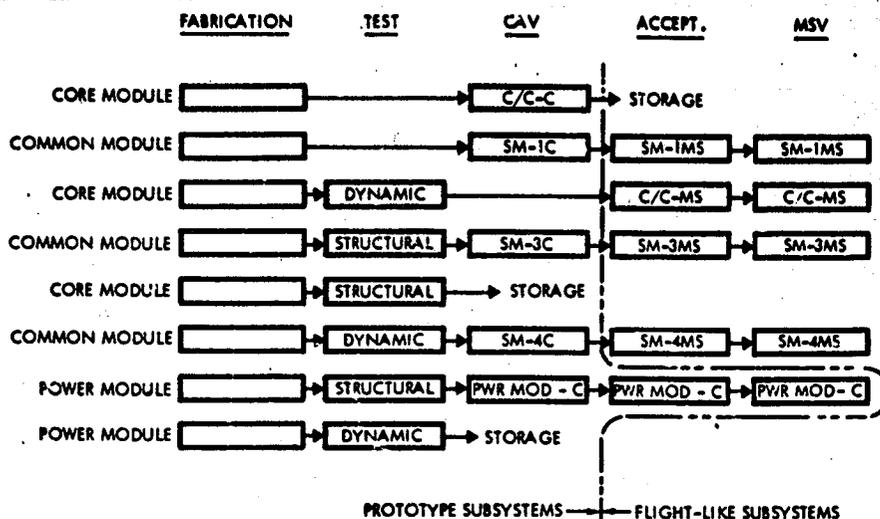


Figure 11. Major Test Hardware Utilization and Flow

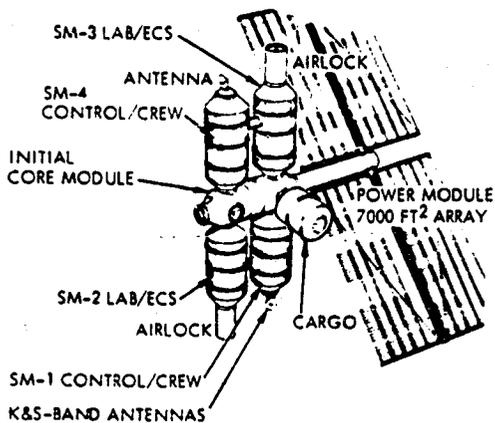
The buildup of the mission support vehicle (MSV) from modules used in the factory acceptance phase is also shown in Figure 11. The MSV is a multipurpose fixture located at the launch site and designed to provide support for the orbital operations throughout the life of the space station. It is maintained in the same configuration as the on-orbit station. Some of the basic functions this set of modules will perform are (1) acceptance of the last three modules comprising the initial station configuration (SM-3, SM-4, and a cargo module); (2) final acceptance of IFRU's, spares, and software revisions; (4) acceptance of RAM's or other experiment hardware having a direct functional interface with the station modules; (5) validation of modifications; and (6) limited crew familiarization.

Cargo modules returned from orbit will be refurbished as required and berthed to the MSV for acceptance. In like manner, any RAM's to be launched for assembly with the orbiting station will have all interfacing functions verified in the MSV prior to launch. Experiments installed in the RAM's not having a functional or dynamic interface with the station will have been accepted before integrated tests in the MSV, and will not be operated during the RAM/MSV integrated tests.

CONFIGURATION

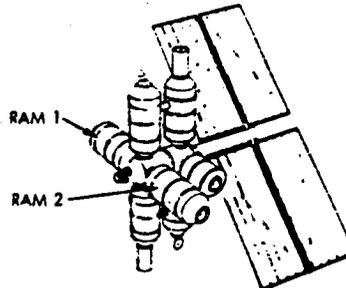
The modular space station configuration is arranged for an initial operational capability, at a crew size of 6, with provisions for addition of modules to operate with a crew size of 12. The initial station configuration (Figure 12) consists of four common station modules, power and core modules, and a cargo module. The station modules are assembled on the core module in a single plane (Z axis), which is normally vertical to the earth's surface. The two laboratory modules have experiment airlocks attached at the outer ports; one provides zenith or celestial pointing for experiments, the other earth pointing (nadir) along the local vertical. The two crew/control modules have removable packages attached at the outer ports that contain K, S, and VHF band antennas.

The power module is designed for solar array replacement by removing the turret and arrays from the module. The 7000-square-foot array is replaced by a 10,000-square-foot array in the growth station configuration.



- MODULES
- FOUR COMMON STATION MODULES
 - TWO SPECIAL MODULES
 - ONE CARGO MODULE
- ASSEMBLY/REPLACEMENT
- MANIPULATOR BERTHING
 - ON ORBIT REPLACEMENT ANTENNA PACKAGES, EXPERIMENT AIRLOCKS & SOLAR ARRAY

OPERATIONAL CONFIGURATION WITH TWO ATTACHED RAMS



VOLUME ALLOCATION	
EXPERIMENT ACTIVITY	7649 FT ³
CREW/SUBSYSTEMS	10,648 FT ³
COMMON USAGE	6363 FT ³

Figure 12. Modular Space Station Configuration (Initial Station)



The cargo modules are docked in the Y plane, alternately on one side of the core, then on the other side on successive cargo deliveries. Cargo modules normally use the core module ports nearest the power module. The other ports are available for operation or service of RAM's. The operational configuration varies as RAM's are added or returned to earth.

The initial station has provisions for accommodating at least two RAM's operating in either an attached or detached mode. The figure shows an operational configuration in which two RAM's are attached. The initial station also has provisions for accommodating many multidiscipline experiments in the general-purpose laboratories in the station. The basic design approach was to provide general-purpose laboratory facilities with functional capability to support a variety of experiments. The common laboratory functions defined are implemented in the station modules. Utilities, equipment, and operating volume are provided for all experiments not assigned to a RAM.

Application of safety criteria during the trades and preliminary design resulted in a station configuration with dual habitable volumes, with inhabited station modules connected with flexports to adjacent modules to provide alternate shirtsleeve passageways. The combination of an auxiliary access and a single station module also provides backup airlock capability for IVA between volumes as well as EVA where the normal EVA/IVA airlock might be inoperable.

Subsystem redundancy and installation in the two pressure volumes provide habitability, life support, and station control with any module or volume lost due to depressurization, fire, or presence of hazardous atmosphere. This design approach provides capability of mission continuation in either volume.

In the configuration arrangement, modules SM-2 and SM-4 with one-half of the core module make up one of the redundant volumes. Modules SM-1 and SM-3 make up the other volume. An EVA/IVA airlock is provided in the core module between the two volumes.

Commonality

The basic station module design approach considered commonality of functions, equipment design arrangement, and structures to achieve low cost and accommodate module replacement. Through module commonality, manufacturing, checkout, and maintenance (both on-orbit and ground) tasks are simplified. The commonality of functions and arrangement achieved is shown in Figure 13. There are two basic types of modules: type A, which primarily contains crew quarters and station control, and type B, which primarily contains general-purpose laboratories and environmental control equipment. The station configuration has one type A and one type B module in each isolatable volume.

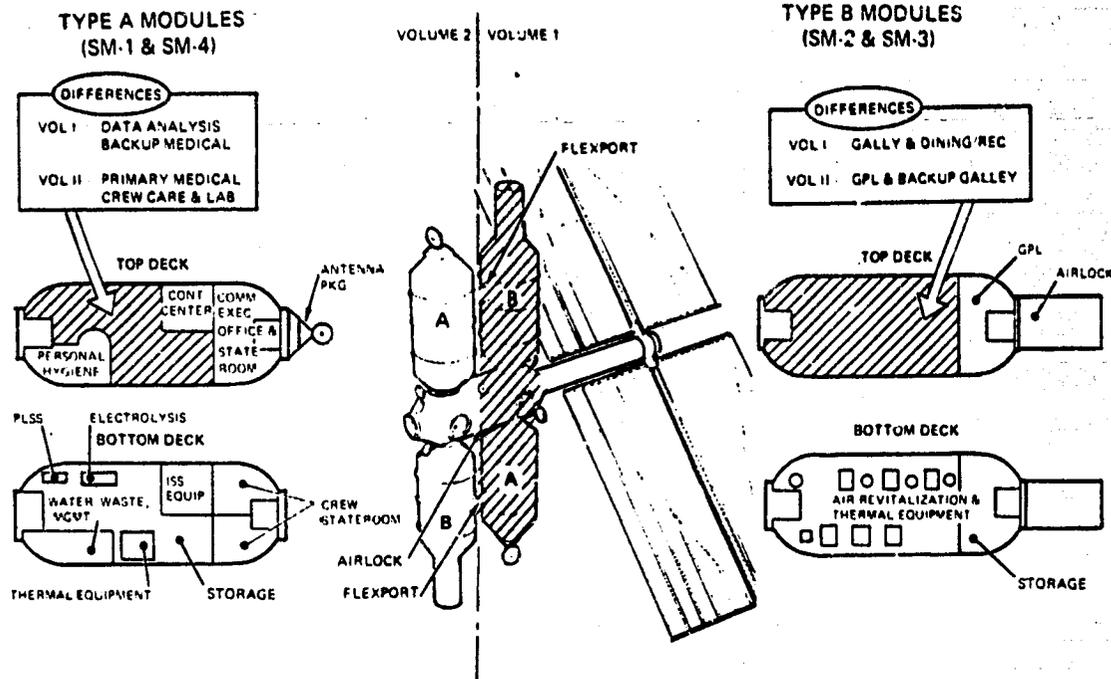


Figure 13. Station Module Commonality

Each module performs a similar function in each of the two pressure-isolatable volumes. Where a primary function is provided in a module, a backup function, when required, is provided in a similar location in the module for the opposite volume. For example, the primary galley is in SM-3 (volume 1) and a backup galley in SM-2 (volume 2); both are type B modules. The control center in SM-1 and a backup control center in SM-4, both type A modules, are identical installations.

The design approach to commonality includes a standard berthing port interface between all modules and a universal structural design for the station modules. The structure for all of the station modules (Figure 14) is 38 feet, 8 inches long between berthing interfaces and provides a 13-foot, 8-inch clear inside diameter. The external frames and attach points extend to 15 feet. An active berthing port is provided at the core module interface and a passive port at the other end. The interface provisions across the berthing ports are identical. Each module contains four manipulator sockets for shuttle deployment and four shuttle bay attach fittings. Radiators cover the exterior of the cylindrical portion of the modules. The radiators and thermal and meteoroid protection installation are identical for each of the station modules.

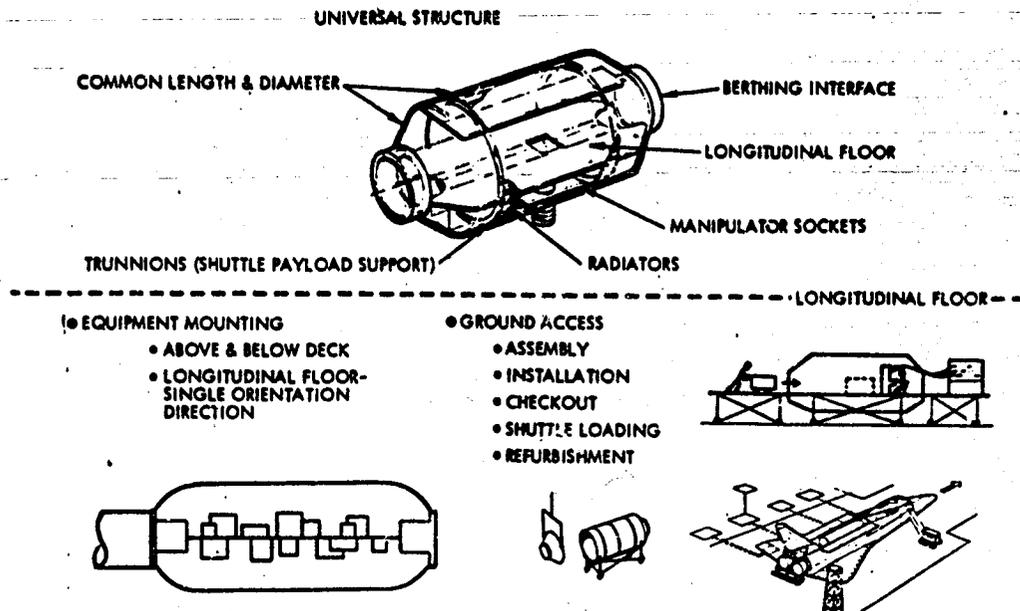


Figure 14. Structure Commonality

Structural Concept

The longitudinal floor provides a single structural component for mounting of equipment both above and below decks, greatly simplifying the manufacturing installation and design details. The longitudinal orientation also simplifies other ground operations of module assembly, checkout, and shuttle installation.

Special Modules

The initial station configuration contains two special modules: a power module and a core module. The power module (Figure 15) consists of two major assemblies, a power boom and a solar array assembly. These two assemblies are connected through a standard berthing port which allows the solar array to be replaced on-orbit. The 88-inch-diameter boom allows the solar array panels to stow within the 15-foot-diameter shuttle payload envelope. The boom diameter also allows access for maintenance of the orientation drive and power transfer mechanisms. High-pressure gas storage bottles for repressurization are installed in the nominally unpressurized boom.

The 40-foot-long core module (Figure 16) is constructed with lightweight skin and stringers, and contains three pressure-isolatable compartments. One compartment, the EVA/IVA airlock, is located in the center and provides access to either of the two habitable volumes. The light side-berthing ports are spaced 20 feet apart, which allows a 5-foot clearance between the station modules.

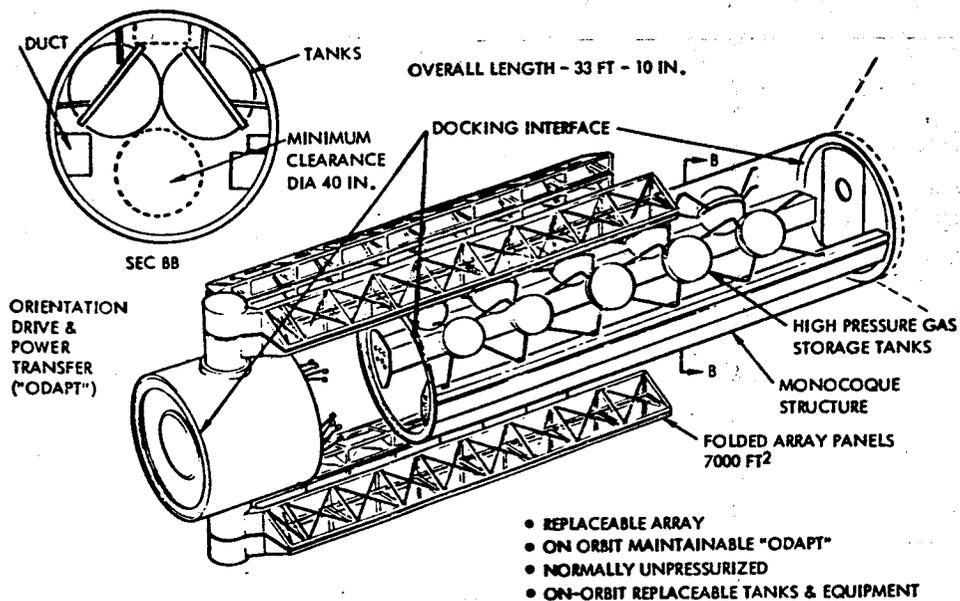


Figure 15. Power Module

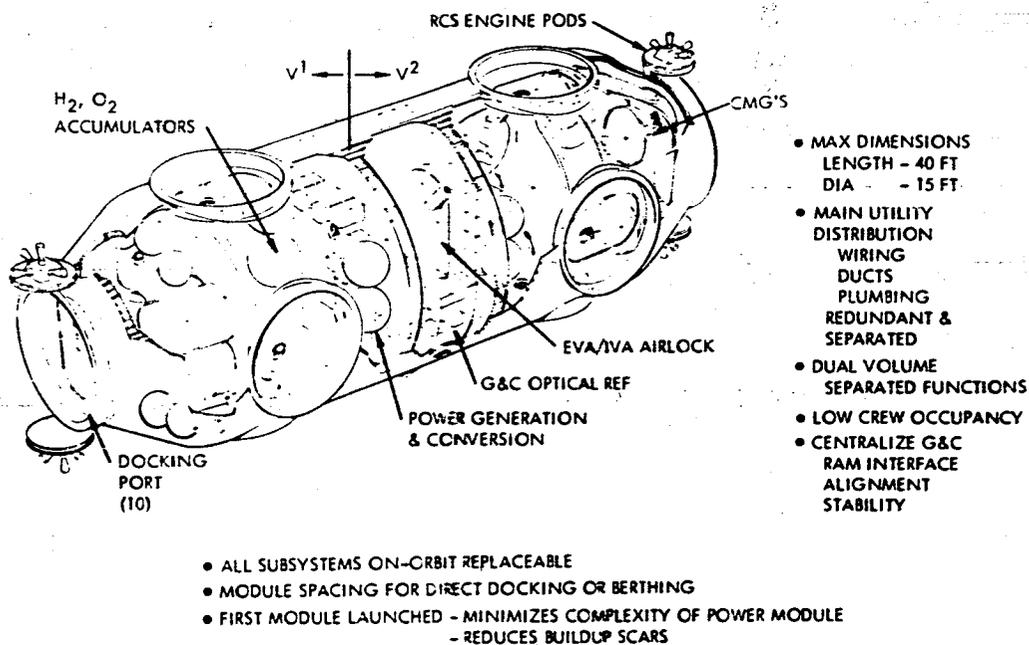


Figure 16. Core Module



Installation and Habitability

All subsystems components are installed for on-orbit maintenance and the utilities routing from port-to-port and end-to-end are redundant and separated for damage containment and safety. All of the guidance and control and the reaction control subsystem assemblies are located in the core module for normal mission operations. Since the core module is the first module launched, certain buildup equipment is installed. Communication wakeup receivers and antennas as well as the thermal radiators are installed for buildup and are not used in normal operations. The secondary power and gas storage tanks are installed and are used for both buildup and normal operations.

Habitability, a major consideration, is designed into each of the station modules to provide comfort, a familiar environment, and special conveniences.

An updirection from all floors of each module is the same direction throughout the station to eliminate reorientation from location to location. Privacy is provided, yet areas are left as open as possible to create a sense of spaciousness. Rectilinear facility shapes are used and all interior equipment is installed in an upright (earth-like) orientation.

Station Modules

Modules SM-1 and SM-4 (Figures 17 and 18) contain the crew living quarters and personal hygiene areas. The stateroom accommodations, for three crewmen, are the same in both modules, a large stateroom above and two staterooms directly below. The commander and chief scientist have additional areas for office and conference functions. A small control console is also installed in these staterooms. Each of the smaller staterooms has remote terminal monitoring and communication units. Hygiene areas are located at the end of each module opposite the crew quarters. Below deck, all of the waste management equipment is installed. An operations control console is installed outside of the commander/executive staterooms in each module. Under nominal station operations, at least one of the two consoles is available for full-time use for control of experiments in either the GPL areas or in attached or detached RAM's.

General-purpose laboratory areas for photoprocessing and data analysis are contained in SM-1. The data analysis area has the capability for review and analysis of both film and taped data. A separate control console is provided for display of data being analyzed and for control of and support to the data analysis processes. The isotonic exercise area in SM-1 also serves as the backup medical area. Installation and storage is provided for both functions.

Figure 18. Station Module 4

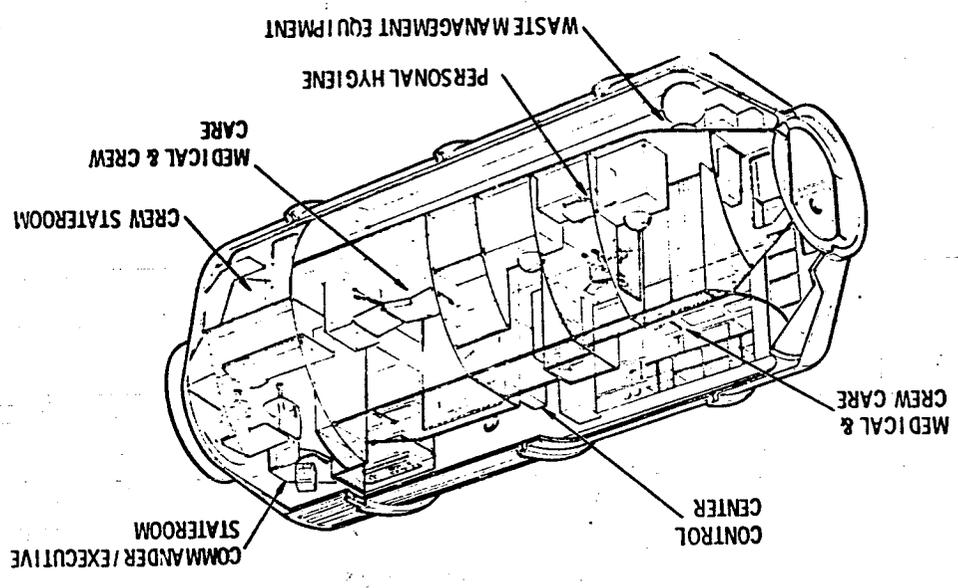
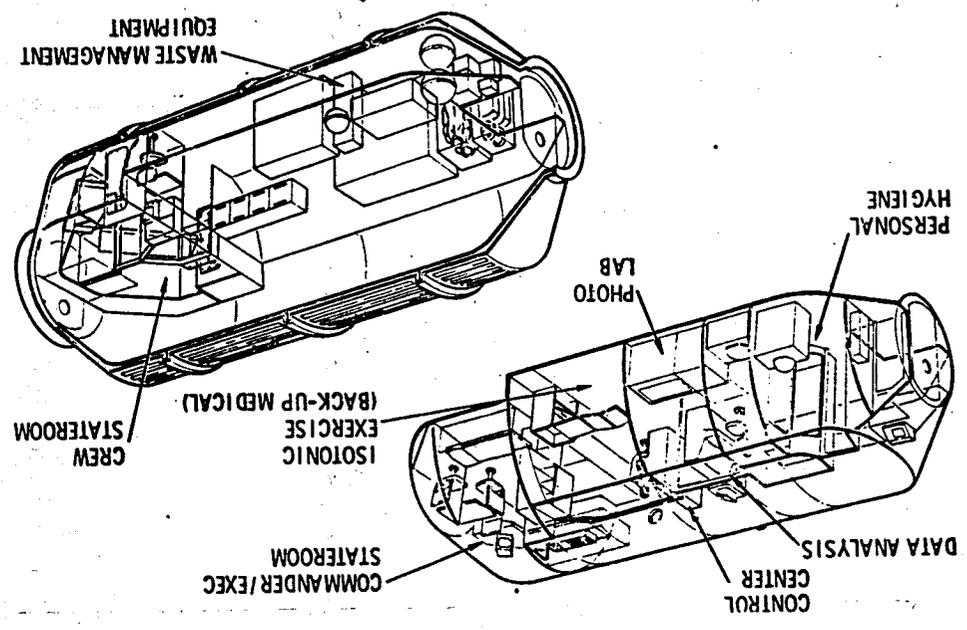


Figure 17. Station Module 1





The upper deck of SM-4 contains the crew care and exercise area. An isolatable medical area for specialized care for ill or injured crewmen is located across from the control center. It is complete with diagnostic equipment and has separate air vent and temperature control. A medical work area opposite the hygiene area provides capability for crew stay time qualification and general-purpose laboratory support for life sciences experiments.

All of the air revitalization equipment needed for the crew of six is located below deck in SM-2 (Figure 19). A redundant set of equipment is located in SM-3 (Figure 20). The remainder of the lower deck area is for storage. The installation of equipment is identical in both modules.

The outboard ends, above deck, are also alike with experiment airlocks attached and GPL area inside. When the airlock of SM-2 (earth pointing) is operated as an earth observations laboratory, the GPL near the airlock is used to assemble equipment groups for transfer to the airlock. A portable control console is available for the operator's control and monitoring of equipment. The remaining upper deck area contains general-purpose laboratory equipment for calibration and service of mechanical, electrical, electronic, and optical experimental equipment. A small backup galley is installed on the inboard end of the upper deck.

The GPL area in SM-3 is primarily a physics laboratory and has access to the zenith-pointing airlock. The remaining upper deck area contains the primary galley and the dining and recreation facilities.

SUBSYSTEMS

The equipment required by the space station system was grouped into seven subsystems: structural and mechanical; environmental control and life support (ECLSS); electrical power (EPS); guidance and control (G&C); reaction control (RCS); information (ISS); and crew and habitability. The preliminary design of each is summarized in the following paragraphs. In addition, two major trades and analyses are described: integrated subsystem trades and thermal integration trades.

Integrated Subsystem Trades

The Phase B MSS studies were initiated with a NASA-imposed level 1 guideline to emphasize cost in the selection process. The guideline stated: "Total cost of the program is a primary consideration. Primary emphasis is on minimum cost to IOC." In an effort to satisfy this guideline, it was decided to conduct the RCS, EPS, and ECLSS selection trades and analyses as for an integrated single subsystem.

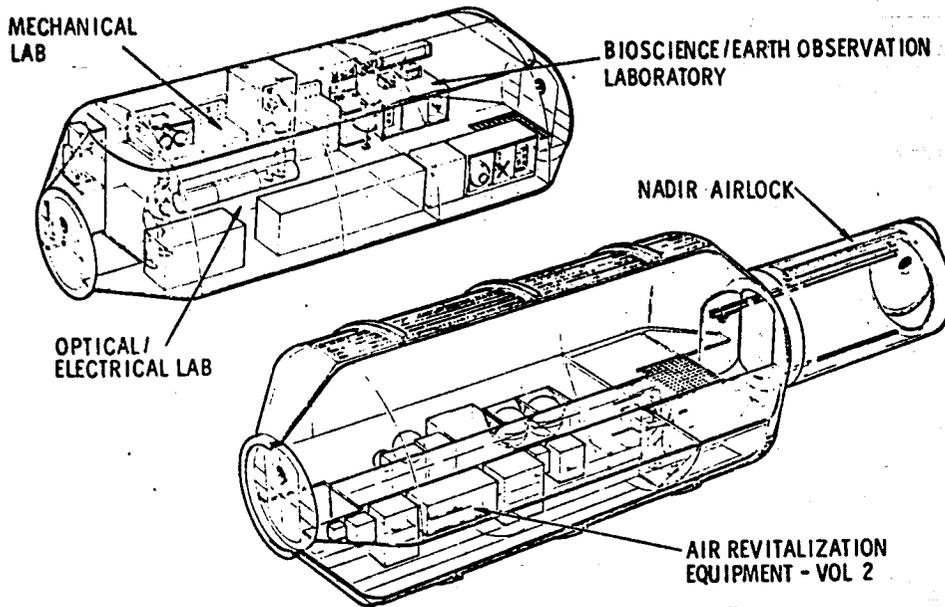


Figure 19. Station Module 2

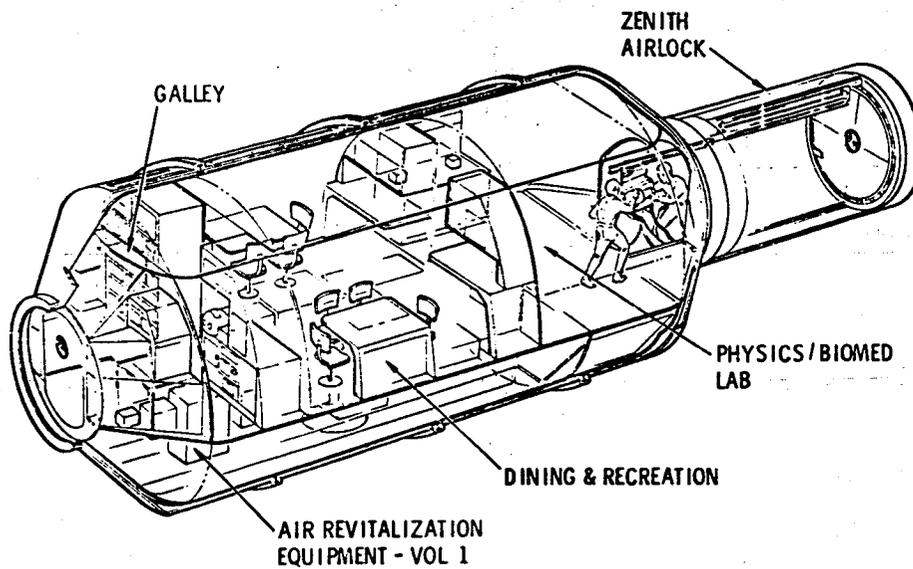


Figure 20. Station Module 3

The integrated subsystem concept options were established by first defining low-cost options for each of the subsystems. Trades of these options at the individual subsystem level deleted those options that could not satisfy the MSS requirements or which imposed large drivers or constraints on MSS configuration and mission operations. A matrix of compatible integrated concept option sets (Figure 21) were constructed from the remaining subsystem options. Thirteen major sets involving many suboption sets (41 sets total) were identified.

Technical and impact analyses trades were conducted at the integrated subsystem level. These trades, shown in Figure 22, reduced the matrix from 41 to 9 concept option sets.

The nine remaining sets include:

1. Three cryogenic H_2-O_2 options with closed or open O_2 ECLSS, and with NiCd batteries or regenerative fuel cells (1-1, 2-2, 3-8).
2. Four-hydrazine RCS concept option, again with open or closed O_2 ECLSS, and with NiCd batteries or regenerative fuel cells (5-3, 6-1, 6-3, 6-4).
3. Two H_2O electrolysis RCS concept options with regenerative fuel cells, and with open or closed O_2 ECLSS (8, 11-2).

Cost was the major evaluation factor. The trades were initiated on the basis that two cost comparisons would be developed: (1) low development costs at IOC of the initial station, and (2) initial station low development cost plus 5-year operations costs. It was initially hoped that the same selection would result from either cost criteria, but it was soon evident that this was not the case. An integrated subsystem based on only low development costs resulted in selections such as open oxygen and water cycles for the ECLSS; Skylab technology solar array panels; non-automated subsystem controls, onboard checkout, fault detection, isolation; 28-vdc electrical power system; and short component life with high maintenance. The result to the MSS program would be high logistics costs, large manpower requirements for station operation, poor habitability, and low program operational flexibility. It was therefore decided to select the concept options and to complete the trades, with the major evaluation factor being initial station low development plus 5-year operational costs. The nine concepts of Figure 22 were costed and compared to make the low-cost subsystem selection. The cost comparison results are shown in the bar graph of Figure 23. The shaded areas represent the development cost comparison and the unshaded areas represent the five-year operational costs.

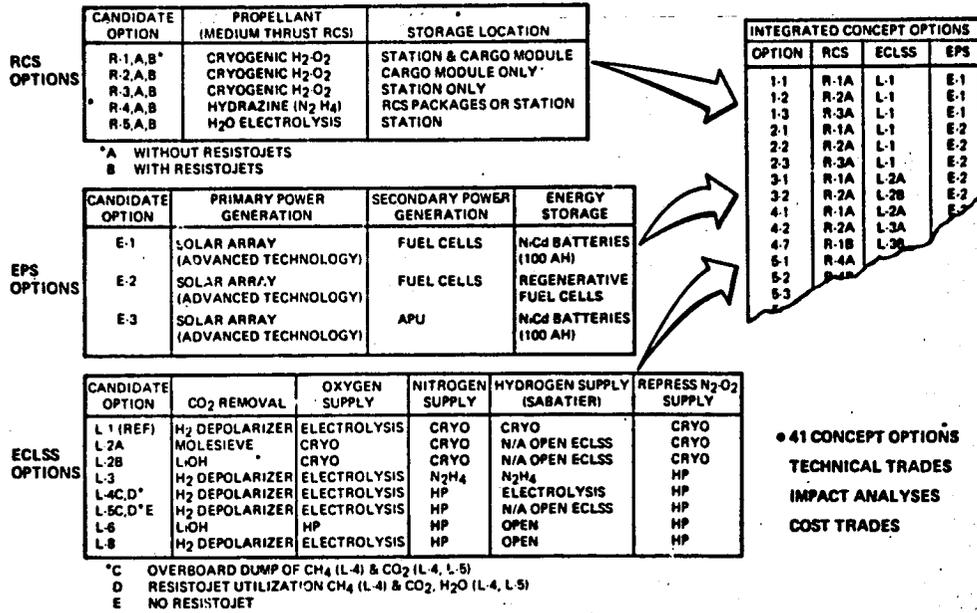


Figure 21. Integrated Subsystem Concept Options

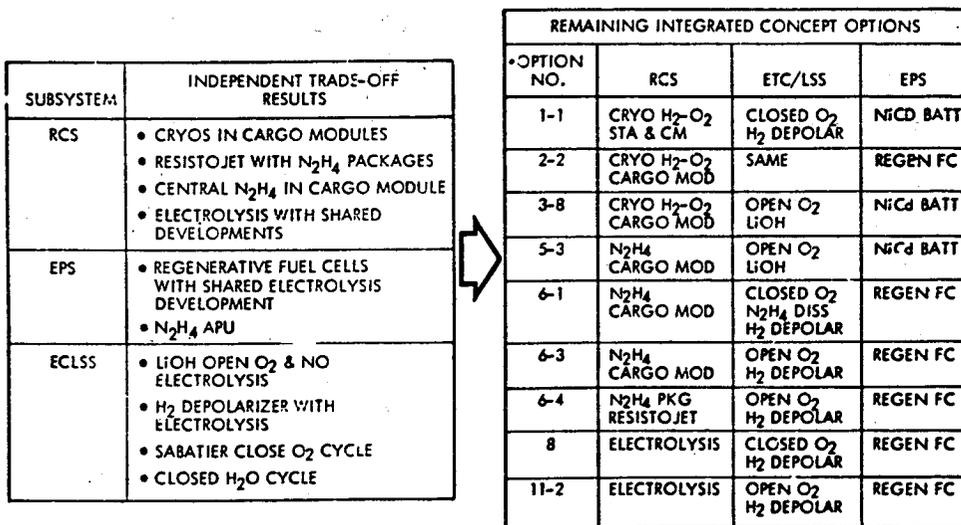


Figure 22. Integrated Subsystem Technical Trade Summary

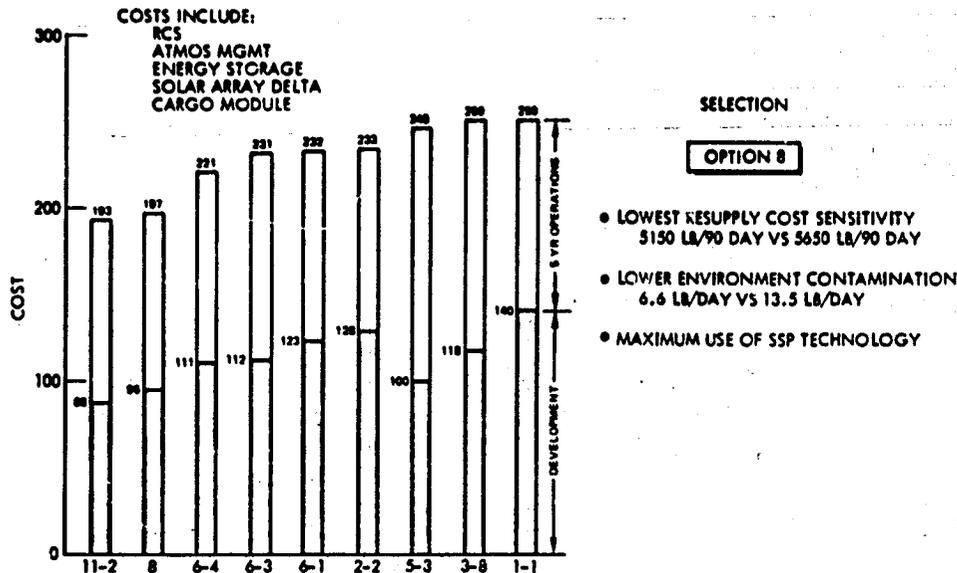


Figure 23. Integrated Subsystem Cost Comparison

Concepts 11-2 and 8 are the lowest cost concepts. Concept 11-2 is an open O₂ ECLSS in that CO₂ reduction (Sabatier) hardware has been deleted and the CO₂ vented overboard at 12-hour intervals. This increases the high-pressure oxygen storage and resupply requirements and, therefore, this concept is sensitive to logistics cost changes. A major disadvantage is the higher venting rates and potential contamination for experiments (13.5 lb/day for 11-2 vs 6.6 lb/day for concept 8).

Concept 8 with the closed O₂ ECLSS reduces these disadvantages and was therefore the selected EPS/RCS/ECLSS integrated subsystem concept. The schematic and the assignment of major hardware to the various subsystems are portrayed in Figure 24.

The EPS will utilize four regenerative fuel-cell assemblies (two for each volume supplying Bus A and Bus B), each consisting of one fuel cell, electrolysis unit, H₂ accumulator, O₂ accumulator, and one-half of an H₂O storage tank. The assembly can receive and supply (in an emergency) H₂, O₂, or H₂O to the ECLSS and RCS.

The ECLSS is a closed O₂ and H₂O concept consisting of an H₂ depolarizer for CO₂ removal, Sabatier for CO₂ reduction, electrolysis for O₂ recovery and for RCS H₂/O₂ generation, and vapor compression for H₂O reclamation. High-pressure storage in nonhabitable areas (cargo modules, power module) was established as the method of resupply.

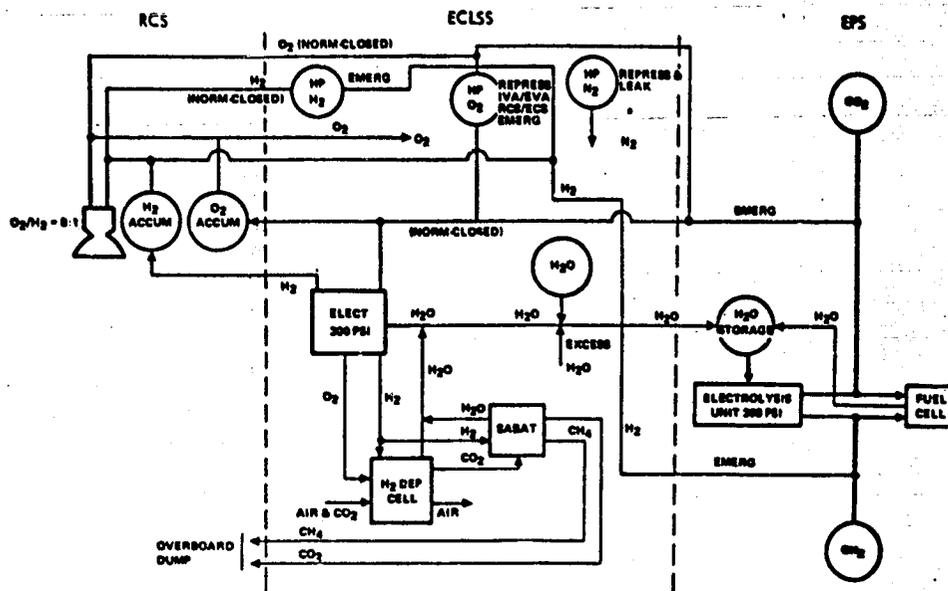


Figure 24. Integrated EPS/RCS/ECLSS Subsystem Selection

The RCS stores H_2/O_2 gases generated at 300 psia by the ECLSS. The oxidizer/fuel (O/F) ratio has been changed from 3:1 to 8:1, which is the combination ratio of O_2 and H_2 , in order to minimize venting.

The integrated subsystem uses an integrated gaseous storage concept at 300 and 3000 psia and an integrated water supply.

Thermal Control Trades

Nineteen alternative thermal control concepts were evaluated for possible application to the modular space station design. These alternatives included applications of heat pipes, louvers, refrigeration assemblies, and deployable and body-mounted radiators.

Significant conclusions reached during the study in addition to the selection of a thermal control concept for the MSS are as follows:

1. Emphasis on cost as a selection criteria significantly favors previously developed concepts over more innovative but undeveloped concepts.



2. Deployable radiators singularly offer solutions to most of the weaknesses of other thermal control concepts. This concept is totally insensitive to vehicle orientation and thermal coating degradation. It can be replaced without impacting the basic function of the space station, allowing maintenance to occur easily on the ground. However, no reasonable location for such radiators was found, considering requirements for antennas, solar arrays, and deployed experiment sensors.
3. Independent active thermal control in which each module has its own assembly is more costly, less flexible, and less reliable than a centralized thermal control concept. It is feasible only when core modules have low heat rejection requirements and when subsystem allocation among modules can be constrained by the heat rejection capability of each module.
4. Single active loop concepts offer the cheapest thermal control concepts; however, a transport fluid that meets all performance requirements without potential impact to the operation of other subsystems could not be found.
5. Passive concepts offer high reliability and simplicity of control. Effective rejection areas can be selected by shutting down ineffective radiator tubes automatically by using gas-filled heat pipes. Elimination of pressure hull penetrations is also feasible with the aid of heat pipes. However, potentially high development costs, particularly in system-level integration aspects, are not consistent with the low-cost objective of the modular space station.

Considering all of these factors with cost as the primary driver, a dual loop, water/Freon 21, active thermal control concept utilizing body-mounted radiators was selected. A water loop is employed in each module to provide equipment temperature control, a heat sink atmospheric temperature control, and humidity control heat exchangers. The water loops of each module are placed in a parallel flow arrangement to form a single central loop approach. The water loop interfaces with the Freon 21 (F21) heat rejection through intercoolers. The energy absorbed by the F21 loop is rejected to space by radiators mounted on the exterior surface of the four station modules. Insulation between the structure and environmental shield and on exterior structural elements such as docking ports and windows was used to control the loss and gain of energy to and from the space environment to reasonable limits.



To meet buildup equipment thermal control requirements a water loop, F21 loop, and intercooler are installed in the core, with a small radiator located on the exterior surface of the core. The intercooler used in buildup thermal control loops is also used to meet emergency power situations. However, an additional water pumping unit is required.

The water loop is redundant in each module for that equipment performing a critical function. The F21 loop has complete redundancy of fluid lines and ability, if required, to operate the entire radiator area for either intercooler. In addition, the redundant radiator tubes can be used with either primary or secondary F21 distribution manifolds. Water was selected to eliminate a toxic hazard problem in the event of coolant loss to the cabin atmosphere during maintenance or equipment failure. Freon was selected as an external loop coolant to minimize potential freezing problems during buildup or any extreme low heat-load condition. The potential toxic problem of Freon has been recognized and appropriate design solutions have been implemented.

Subsystem Design

The following subsections summarize the preliminary design of the initial space station subsystems.

Structural and Mechanical Subsystem

The modular space station structural arrangement consists of an assembly of modules structurally attached to form a rigid space structure. The space station is assembled from three basic modules: power module, core module, and station modules. The power and core modules are unique in design. The structural concept as well as the equipment and internal arrangements are different for these modules. Station modules utilize a common primary structural design with different internal arrangements, secondary structure, furnishings, and subsystem equipment.

The station module primary universal structure (Figure 25) is designed so the basic structural element reacts all primary loading conditions such as berthing, pressure, and shuttle cargo bay. This allows maximum flexibility in the internal architectural arrangement of equipment and functions. The basic structural element can then be utilized with longitudinal floors, transverse floors, or no floors. The sidewalls and end bulkheads are of pure monocoque construction made from 0.145-inch 5052-H34 aluminum. The internal diameter is 164 inches and is completely free of any protuberances.

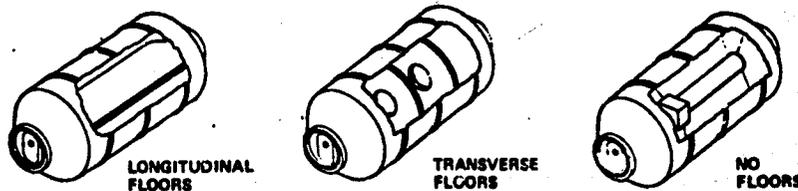
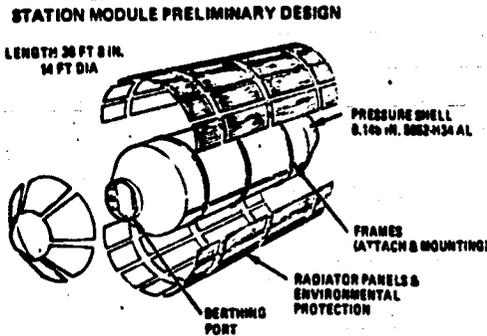


Figure 25. Station Module Structural Configuration

Doors and hatches provide crewman passage from one habitable volume to the other, from the core module to space via the airlock, and from the core module to the station modules. These hatches, when closed, must provide a pressure seal interface for the structural subsystem.

The auxiliary access port provides the means for satisfying the safety criteria for dual egress. In the event of an accident in any one station module, the crewmen have access to the safe volume by two routes: through the core module and through the auxiliary access port.

The environmental protection assembly provides three basic functions. The primary driving considerations for temperature and heat load control are to establish (to the extent practical) thermal independence of attitude, to preclude condensate formation on interior surfaces, and to limit external environment heat loads to the station and losses from the station. Long-term



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protection from meteoroids is required for all external structures. The meteoroid bumper is supported with nonmetallic fasteners for thermal isolation. A double-bumper configuration offers maximum efficiency for meteoroid protection. The protection of the crew from radiation includes evaluation of the natural sources, earth-trapped, cosmic-galactic, and solar-flare radiation. The radiation shield utilizes the primary bumper and the mass of the structure and furnishings for protection of the crew from the natural radiation environment. A station module skin thickness of 0.145 inch of aluminum plus the environmental shield primary meteoroid bumper of 0.030 inch of aluminum provides radiation protection of 1.25 grams per square centimeter. Adequate protection is provided by the monocoque structure for earth-trapped and galactic-cosmic particles. However, goggles are required for the eyes during solar flare events.

To facilitate crew operations and efficient use of equipment, the general-purpose laboratory has several functional areas placed in suitable locations throughout the basic station. These areas (for the initial station configuration) are airlocks, medical/biological, physics, dated analysis, optical supply and maintenance, electrical/electronics maintenance, photographic processing, and mechanical maintenance.

The initial station dedicates 824 square feet of floor space to GPL furnishings. Station modules accommodate 704 square feet and the experiment airlocks account for 120 square feet.

Environmental Control and Life Support Subsystem

The ECLSS provides for gaseous storage, CO₂ management, atmospheric control, thermal control, water management, waste management, hygiene, and special life support. In addition, the electrolysis units of the CO₂ management assembly are used to supply the RCS propellants.

The dual pressure volume (V_1 and V_2) requirement, in conjunction with the failure criteria for the MSS, established the ECLSS redundancy and equipment sizing requirements for dual six-man equipment. The 3.0 mmHg pp CO₂ requirement, in conjunction with the 12-hour experimental no-venting requirement and minimization of electrical power, drove the CO₂ removal selection to a hydrogen depolarizer concentrator concept. The on-orbit repressurization requirement of one pressure volume of the MSS drives the high-pressure gas storage assembly to large volumes. The ECLSS also has several requirements to provide experiment support. These include thermal control, water and waste management, and atmospheric makeup. The ECLSS equipment location is shown in Figure 26.

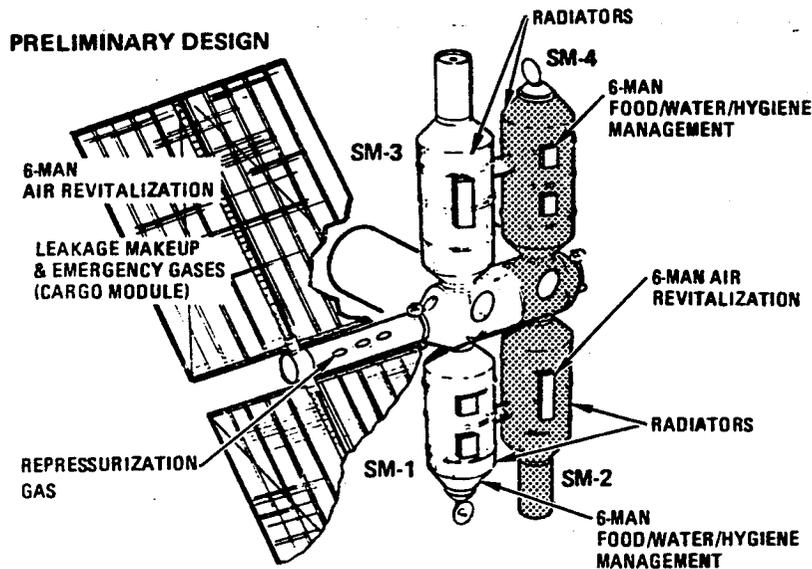


Figure 26. ECLSS Equipment Location

The gaseous storage assembly utilizes high-pressure (3000 psia) gas storage tanks for the N_2 , O_2 , and H_2 requirements of the ECLSS, EPS, and RCS. All high-pressure storage is in normally nonhabitable volumes of the MSS. The N_2 and O_2 repressurization gases and the EPS fuel cell O_2 and H_2 reactants for the second 30-day buildup phase are stored in the power boom. The N_2 leakage makeup, the EPS/RCS emergency O_2 and H_2 , and the ECLSS emergency, EVA, and prebreathing O_2 consumables are stored in the cargo module.

The CO_2 management assembly uses an H_2 depolarizer CO_2 concentrator for CO_2 removal, a Sabatier unit for CO_2 reduction, and solid polymer H_2O electrolysis for O_2 recovery. The electrolysis units are used to provide the RCS H_2 and O_2 propellant gases and can also be used as backup for the EPS regenerative fuel cell energy storage assembly. Each pressure volume contains a 96-hour emergency supply of $LiOH$ for CO_2 removal while emergency oxygen is retained in the gas storage assembly.



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The atmospheric control assembly uses a central humidity condenser to satisfy the 8 to 12 mmHg water vapor requirement. Contamination control utilizes nonregenerable charcoal and catalytic oxidizers. Monitoring uses both gas chromatograph and mass spectrometer concepts.

The thermal control assembly consists of an active central dual coolant loops (H₂O internal, Freon 21 external) concept with heat rejection from 180-degree segmented radiators mounted on the station modules. A small radiator is included on the core module for the buildup heat rejection requirements.

The water management assembly uses vapor compression units for water reclamation. Water purity is maintained thermally (160 F) and by silver ion generation. Resupply water storage is maintained on the cargo module and processed water is stored in the potable water tanks in the station modules. Water storage is also available in the EPS regenerative fuel cell energy storage tanks.

The waste management assembly uses a "dry John" toilet with wall-mounted, water-flush urinals. Trash compactors are located in the station modules. Waste processing utilizes vacuum drying scheduled during the crew night to minimize venting during experimental operational periods.

Hygiene facilities including full body showers and sinks are conveniently located in the crew/control station modules.

The special life support assembly provides for fire detection and control via condensate nuclei detectors and CO₂ fire extinguishers. Module depressurization can also be used for fire control. EVA PLSS servicing is from the gas storage assembly supplies in the cargo module. IVA air and water provisions are incorporated into the MSS.

Electrical Power Subsystem

The EPS provides for primary power generation for normal operations; secondary power generation for station buildup, emergency, and solar array replacement operations; energy storage for orbital dark periods; power transfer, conditioning, and distribution; and spacecraft lighting.

The solar array primary power generation selection was established by a NASA guideline while the sizing was based on the normal operations power level of 18.7 kw (excluding distribution and conditioning losses). This power level includes 4.5 kw for experiments. Figure 27 illustrates the EPS conceptual equipment location for the MSS.



PRIMARY POWER GENERATION

7000 FT² SOLAR ARRAY
LOCKHEED TECHNOLOGY

ENERGY STORAGE

REGENERATIVE FUEL CELLS

FUEL CELL (SHUTTLE)
RATED POWER - 7.0 KW/FC (4 REQD)

ELECTROLYSIS (ECLSS)

REACTANT RATE - 3 LB/HR (4 REQD)
SPEC PWR CONSUMPT - 2.14 KWH/LB H₂O

ACCUMULATORS

H₂ - 33 IN. DIAM (4 REQD)
O₂ - 26 IN. DIAM (4 REQD)

SECONDARY POWER GENERATION

ENERGY STORAGE FUEL CELLS

HIGH PRESSURE STORAGE

POWER CONDITIONING & DISTRIBUTION

PRIMARY BUSES 240/416 VAC, 400 Hz

SECONDARY BUSES 240/416 VAC, 400 Hz

120/208 VAC, 400 Hz

56 VDC

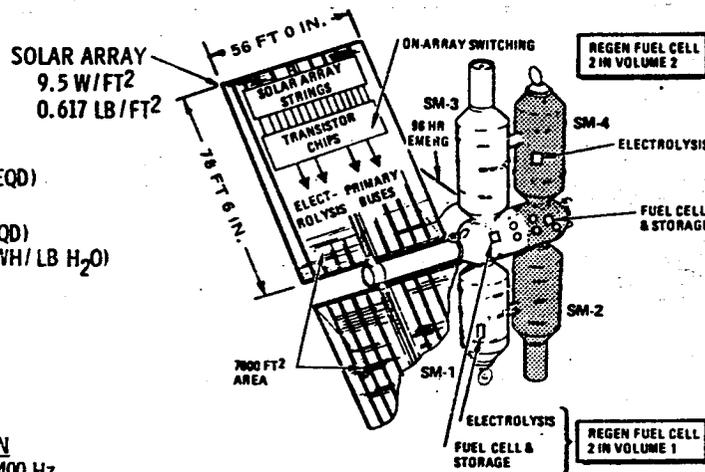


Figure 27. Electrical Power System Equipment Location

The primary power generation assembly is the 7000-square-foot solar array using the Lockheed technology concept. Power switching on the solar array has been incorporated to improve power regulation and power management, and to provide power deadfacing at the interface for maintenance purposes. Energy is stored by four regenerative fuel cell and electrolysis assemblies (one per primary bus). The fuel cells also serve the function of secondary (emergency) power generation when supplied by high-pressure stored gases.

The four primary buses have been selected as 240/416 vac, 400 Hz, 3-phase power. The secondary buses provide both the high-voltage (240/416 vac) and the low-voltage (120/208 vac) 400 Hz, 3-phase power. The selection again was made on cost and availability considerations. The hardware for switching large blocks of power is presently available only for ac power. The fact that commercial and military aircraft are tending toward all-ac systems utilizing computer-controlled solid-state circuit breakers was a main consideration in the selection. This minimized the cost and development risks to the program for inverters, regulators, transformers/filters, solid-state circuit breakers, or switching devices and software.

The initial station core module is compartmentized into a V_1 and V_2 volume. Two primary and secondary buses, two regenerative fuel cell assemblies, and two inverters are located in each pressurized volume. Each station module contains two secondary buses, one from each primary bus of the associated volume. Critical loads are supplied from either secondary bus while noncritical loads are supplied from only one bus.

Special EPS circuits, including an RF wakeup circuit, are provided for the buildup phases. These special circuits are used to meet the unmanned operational requirements before installation of the information subsystem (ISS) and to minimize the power losses that would occur if the larger-power normal hardware were used.

Guidance and Control Subsystem

The G&C subsystem provides for guidance and navigation and stabilization and control of the MSS in conjunction with the RCS. Figure 28 shows the G&C concept and location of equipment.

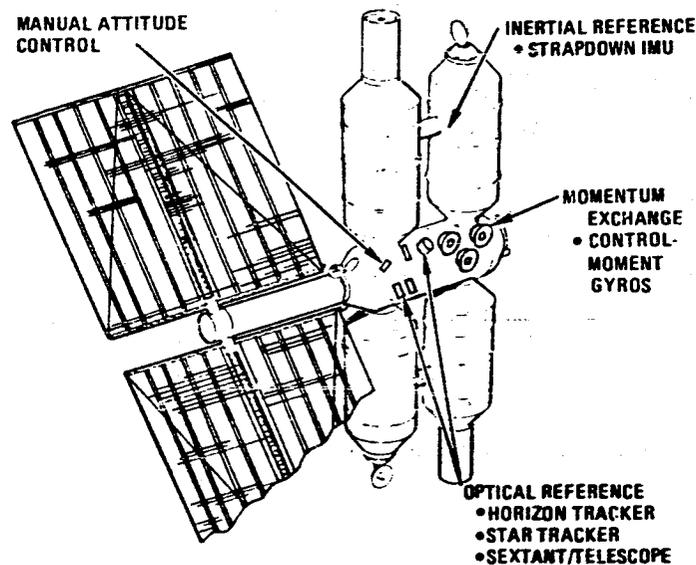


Figure 28. Guidance and Control Equipment Location



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The inertial reference assembly includes a strapdown inertial measurement unit (SDIMU) and a preprocessor. The SDIMU includes six gyros and six accelerometers in a skew-symmetric configuration. This concept provides satisfactory performance with any three gyros working and in fact is more reliable than an orthogonal arrangement of nine gyros.

The optical reference assembly consists of two double-gimbaled star trackers, a four-head horizon edge tracker, a sextant/telescope, three optical alignment units, and a preprocessor. This equipment is used to provide an attitude reference (both local level and inertial), alignment between the G&C equipment and experiment equipment, autonomous navigation measurements, and unknown target tracking for experiment support.

The RCS electronics assembly includes four RCS jet driver electronics units and two preprocessors. The driver units amplify the logic level outputs of the preprocessors to provide operating power for the solenoids and ignitors of the RCS jets. Each preprocessor is hardwired to all four quad driver units and either is capable of controlling the vehicle without relying on the other. The preprocessors provide limited failure monitoring for the RCS.

The momentum exchange assembly includes a planar array of three double-gimbaled control moment gyros and a preprocessor. The angular momentum of each gyro is 1100 ft-lb-sec. The array will provide momentum exchange with one gyro down for repair. The CMG's are designed for on-orbit repair at the subassembly level. The CMG's are desaturated using the RCS or when operations permit using gravity gradient torques.

The computation assembly represents the software for the G&C computations performed within the ISS. These computations are in general highly interrelated with other computations performed by the ISS to support such functions as flight control and experiment operations.

Local level mode attitude control is accomplished using the star trackers and horizon trackers as the attitude reference. Yaw attitude is computed from star tracker data and angular rates are derived from the attitude signals. Control torques are obtained from the CMG's, which are desaturated using either the RCS or gravity gradient techniques. This mode is completely automatic. Crew attention is only required in case of an indicated failure.

Inertial mode attitude control is performed as described above with the exception of the attitude reference function. The inertial mode attitude reference can be obtained using either the SDIMU or both star trackers simultaneously.



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Emergency power attitude control is the mode used during an electrical power emergency when power is obtained from the fuel cells and the solar array is inoperable. The attitude reference is provided by the SDIMU. Control torques are provided by the RCS and the CMG's are deactivated to conserve power. The optical reference is a potential lower power alternative to the SDIMU. This mode is automatic.

Orbit maintenance translation control is normally conducted simultaneously with local level mode attitude control. The SDIMU is used for velocity measurements and the translation thrusts are applied using the attitude control jets.

Manual control-visual cues is an emergency mode that can be used to perform the only critical G&C function, stabilization for docking. The mode is completely manual using a hand controller and visual out-the-window cues. This control function can be performed from either volume in the core module. The hand controller switches are hard-wired to the RCS electronics driver units, which activate the RCS jets. The only objective in this mode is to provide sufficient rate stabilization for a rescue shuttle to accomplish a docking.

Local level navigation is the primary navigation mode performed autonomously and automatically using star-horizon measurements taken by a star tracker and the horizon edge tracker. The bulk of the navigation computations are performed within the ISS central processor.

Inertial or manual navigation is performed by the manual landmark tracking technique using the sextant/telescope. The SDIMU is used to maintain the necessary inertial reference. This navigation mode can be used in conjunction with the inertial attitude control mode. It can also be used during local level operations as a check on the performance of the nominal navigation mode.

Reaction Control Subsystem

The RCS provides thrust for stabilization and docking, orbit maintenance, CMG desaturation, and maneuvers. In addition, under the integrated subsystem concept, the RCS provides the H₂ and O₂ accumulators, which will store all the gases provided by the ECLSS electrolysis. This includes the orbital dark period H₂ for the Sabatier and the H₂ and O₂ for the depolarizer. The propellant (H₂O) storage has been integrated into the ECLSS (cargo module storage) and/or the EPS (onboard storage).



A major design consideration during buildup is the requirement for capability to stabilize and dock after two failures. In addition, the design requires activation and operation of the RCS via RF communication links (VHF and S-band) from the ground or the shuttle. During manned operations, the capability to stabilize and dock after three failures is required.

The atmospheric model is a driver on the RCS. The impulse numbers identified are based on a 240-nautical-mile, 55-degree orbit and a Jacchia (2 sigma mean) atmosphere. This model, in conjunction with an initial station IOC of January 1982, forms the basis for RCS equipment sizing of electrolysis units, accumulators, and water storage tanks. A nominal 240-nautical-mile atmospheric model is used to define the solar array area penalty associated with the RCS electrolysis. The nominal mission of 270-nautical-mile, 55-degree orbit was used to define the RCS logistics resupply and the RCS average power requirements. The 12-hour no-venting requirement imposed by the experiments was also a driver on RCS accumulator sizing.

The MSS RCS uses a medium-thrust, hydrogen and oxygen gaseous propellant, in-flight maintainable engine quad concept. The H_2 and O_2 propellants are supplied by water electrolysis from the ECLSS. The EPS electrolysis is also integrated into the RCS and can be utilized as a backup supply. The engine quads use 10-pound engines and an oxidizer to fuel ratio (O/F) of 8:1. This is the recombination ratio of H_2 and O_2 and was selected to minimize venting from the station. Some penalty in I_{sp} was accepted (320 at 8:1 versus 419 at 3:1). The engine quads are located on the Z axis of the core modules. The RCS concept including the engine maintenance approach are shown in Figure 29.

Four each H_2 and O_2 accumulators are provided by the RCS. These are located, two each, in modules SM-2 and SM-3. The accumulators are sized for the 12-hour firing intervals during the crew night periods.

The MSS buildup requirements are satisfied by the RCS four-engine quad installation for normal manned operations. For the first 60 days of buildup (core and power module launches), the RCS propellant requirements are supplied from H_2 and O_2 gaseous supplies stored at 3000 psi in the EPS accumulators. With the third launch of module SM-1 and activation of the solar arrays, the RCS propellants are supplied by the EPS electrolysis units.

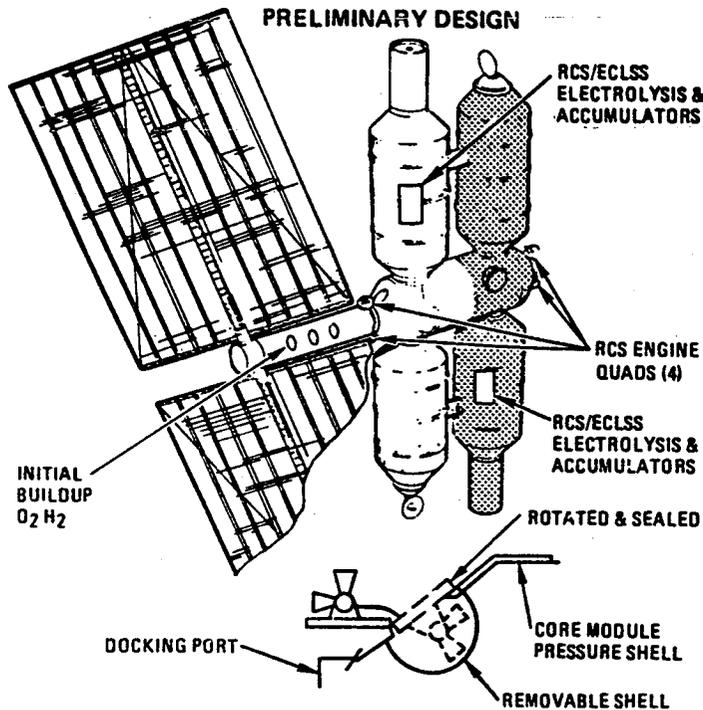


Figure 29. Reaction Control Subsystem Equipment Location

Information Subsystem

The ISS performs functions for the MSS which are necessary to tie the subsystems together as a working unit and provide for the command and control of the station and its experiments. These functions are defined as station operations and experiment management and have been further categorized as operations data management, command and control/flight control, mission planning and operations scheduling, onboard checkout/monitor and alarm, communications management, crew data management, and experiment data management.

The ISS consists of five assemblies of equipment: the external communications, internal communications, data processing, command/control/monitoring, and software.



The external communications assembly (Figure 30) is located in both SM-1 and -4. Each module contains:

1. A parabolic directional antenna-electronic package at K-band for communications with the NASA TDRS. The redundant electronics are mounted on the antenna.
2. Two semidirectional antenna-electronic packages at S-band for wide-angle coverage with the ground, shuttle orbiter, and detached RAM's.
3. Two VHF band antenna-electronic packages for communications with any EVA activity, the TDRS, orbiter, or any object with VHF capability. Communications capability is located in the core module for buildup purposes.

The data processing assembly is located in the control centers in both SM-1 and SM-4. Each central processor (CP) in the DPA is capable of performing the total station operations function. During normal operations, one CP is performing station operations and the second, experiment operations, with enough station data to allow it to take over in case of a complete failure of the first CP. Data processing capability is provided in the core and power module for use during buildup.

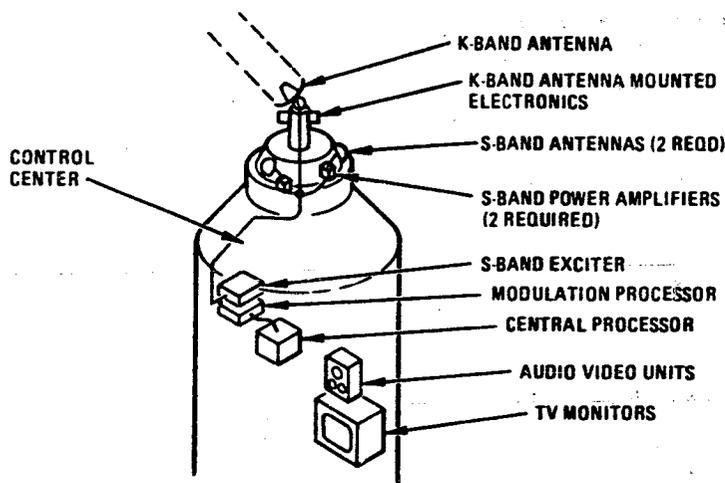


Figure 30. External Communications/Internal Buses

The command/control/monitoring assembly is located in the control centers in both SM-1 and SM-4. Like the DPA, each center can perform station operations with the first normally performing station operations and the second, experiment operations. The commander's console and portable units are used for remote access to the central processor.

The internal communications assembly is located near the control centers in SM-1 and SM-4. Audio-video units are located throughout the station with TV monitors in each stateroom and laboratory area.

Software storage stores the computer tapes, microfilm, and printer paper for station and experiment operation. Storage areas are located near the control centers in SM-1 and -4. The preparation of the computer program is included as if this were an assembly to allow visibility and therefore better control of this significant effort.

Crew and Habitability Subsystem

The crew and habitability subsystem provides the equipment and furnishings required for the well-being of the crew. The subsystem includes the crew and all the equipment and facilities required to support the crew efficiently and help it perform its duties effectively. The space station interior is designed with good architectural and decorator practices to provide comfortable, efficient, and attractive living and work spaces. The long-duration missions envisioned for the space station crew with minimum special training requires an environment similar to that in a normal earth situation.

The food management assembly provides for food storage, preparation, serving, cleanup, and inventory control. The galley equipment must accommodate a large range of food types, cooking operations, and crew use modes. Station meals will consist of a mix of meats, vegetables, fruits, cereals, and beverages provided in bulk and individually packaged form from frozen, dried, thermostabilized (canned), and fresh stores.

Medical and dental equipment and supplies are provided for routine crew monitoring as well as for diagnosis and treatment of injury and illness. The medical and dental equipment includes X-ray, drugs, dressing, bandages, wraps, splints, cold packs and heat pads, body and specimen mass measurement devices, rotating litter chair, laminar flow glove unit, lower body negative pressure unit, biomonitors and display equipment, behavioral evaluation equipment, laboratory analysis equipment, refrigerator and freezer, oven, and sterilizer.



Active and passive-type recreation equipment and supplies are provided for the crewmen. The complement includes color television sets, motion picture projector and screen, film library, reading material, tape deck and library, craft material, table games, and puzzles.

SAFETY ANALYSES

During the Phase B study for the MSS, safety analyses were conducted to determine subsystem failures, accidents, and operational conditions which may endanger personnel or lead to damage or loss of the station equipment. A detailed listing of these hazards is contained in SD 71-224, Modular Space Station Safety Analysis. Essentially, the hazards analyzed consist of loss of primary and secondary structure, tank ruptures, loss of portions of the environmental or thermal subsystems, power generation loss or degradation, and leakages of hazardous fluids. In all cases where hazards exist, design solutions were implemented during the preliminary design to minimize their effects. Typical of design solutions incorporated was the double containment of valves, tanks, and plumbing associated with hazardous fluids. Secondary access paths were provided to facilitate dual ingress/egress requirements. Increased safety factors were applied to tanks located in inhabited modules to minimize rupture potential. A detailed study was conducted on high-pressure gas storage because of the hazard associated with tank rupture. Because it is not possible to eliminate this hazard, adequate means must be taken to minimize the potential effects and to make provisions in case of an accident. Every attempt was made to locate hazardous and toxic fluid storage tanks outside the habitable areas; however, because of limited volume, it was not possible to do this in all cases.

After a detailed analysis, the requirement was established that all pressure vessels located in habitable areas would be designed to a safety factor of 4.0. An additional safety requirement was imposed which limits the volume of all pressure vessels within the space station so that in an event of rupture, overpressurization of the space station structure will not occur. Those tanks located outside of habitable areas will be designed to a safety factor of 2.0.

There are a number of potential emergencies which will require intravehicular or extravehicular activity. The location, size, and number of IVA/EVA airlocks became an important safety consideration and was found to exert influence in the configuration of the modular space station. The most obvious use of an airlock is to allow entry into a depressurized or otherwise uninhabitable pressure volume. An IVA airlock must therefore be located at the interface of the two pressure volumes. Since an accident that causes the requirement for IVA also may result in damage to the airlock, a second means of obtaining access to the affected volume is required. This can be accomplished by one of the modules and the connecting flexport. It is also acceptable for this backup to utilize EVA from modules without flexports.

Similarly, EVA access should be available by at least two independent routes, located or accessible from each of the two pressure volumes. The airlock location for IVA/EVA is shown in Figure 31.

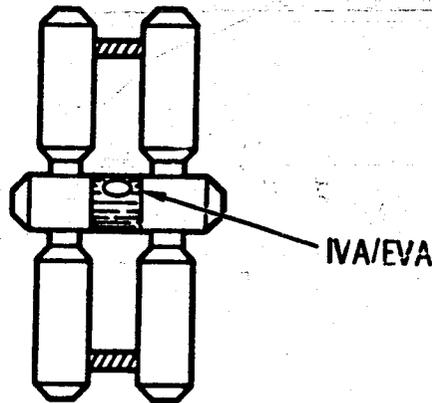


Figure 31. IVA/EVA Airlock Location

An overview of the system safety aspects of the modular space station shows that a high degree of safety exists for both crew and equipment. This has been achieved by a methodical application of system safety techniques during the concept trades and preliminary design. Key design features, such as dividing the station into two separately habitable volumes, provision of escape routes and airlocks for use in emergencies, and increased safety factors and subsystem redundancy, provide a basically safe spacecraft with an increased capability for surviving accidents and emergencies.

MOCKUP REVIEW AND EVALUATION

A mockup of the modular space station was constructed including a partial core module and two station modules to demonstrate the following features:

1. Command and control center
2. Crew sleeping quarters and hygiene areas
3. Food management area
4. Experiment
5. Typical subsystem installations

The location and position of station modules SM-1 and SM-2 with respect to the core module were selected based on minimum cost of construction and to permit efficient viewing during evaluation. Consequently, these module relationships are not representative of the actual initial station module locations. Figure 32 is a photograph of the mockup showing these module arrangements. The formal NASA review and evaluation of the MSS mockup was conducted December 8, 1971 at NR's Seal Beach facility. Review item dispositions (RID's) were not used for this review. Specialty area teams were established including systems and habitability, experiments, and flight operations, which were composed of NASA and NR technical specialists. These teams reviewed the mockup and presented their comments to the Review Board for consideration. These lists of comments were then documented for incorporation into the Mockup Review and Evaluation Document, SD 71-220.

The mockup comments indicated that no major discrepancies exist with the MSS design as presented or with the mockup itself. General comments did indicate that, if there had been adequate funds, a complete core module rather than a partial one should have been mocked up to better present the details of this critical module.

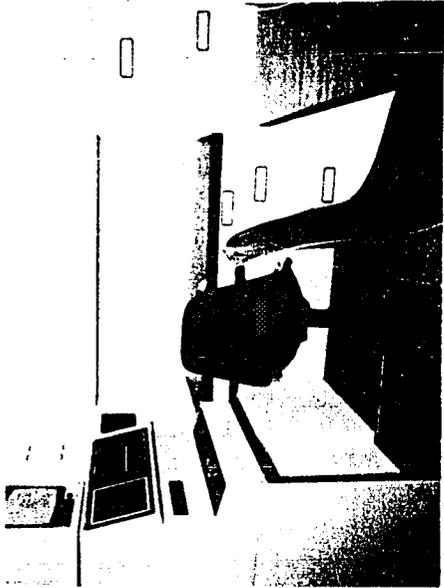
Figures 33 through 35 show significant interior views of the mockup.

GROWTH SPACE STATION

The time-phased capability plateaus established by study guidelines utilized an initial 6-man station for five years followed by growth to a 12-man station. To achieve the 12-man capability, additional staterooms, personal hygiene, and life support system equipment are required. Two additional station modules are utilized for growth and take maximum advantage of accommodation features developed for the initial station.

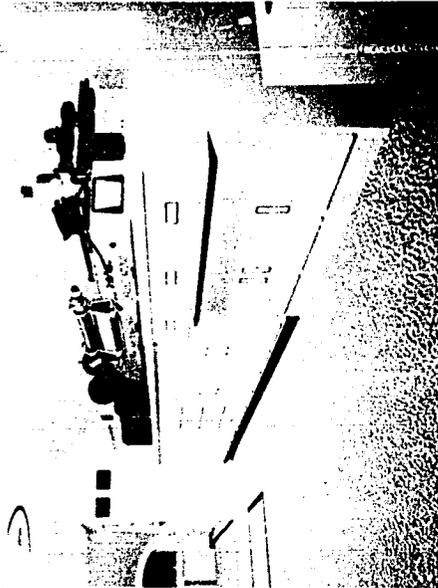
In converting to the growth configuration, the man-hours available for experiment operations increase from 35 man-hours per day to 90. Thus, the growth station requires capability to handle more RAM's and additional GPL provisions to effectively use the increased crew activity. To be equivalent to the 33-foot-diameter station, capability to operate at least three attached and three detached RAM's is required. Additional control consoles are required for extending subsystems and experiment monitoring and control.

To support the six additional crewmen, two personal hygiene facilities with water reclamation equipment are required. The capability to process the atmosphere requires two sets of air revitalization assemblies similar to those in SM-2 and SM-3 of the initial station. The equipment redundancy must be distributed in modules so that capability exists to sustain the full crew in either of the two pressure-isolatable volumes of the station, V_1 and V_2 .



700-04-122D

Figure 33. Commander's Quarters



700-04-122M

Figure 35. SM-2 Interior



700-04-122C

Figure 32. Exterior Arrangement



700-04-122H

Figure 34. SM-1 Interior

The growth station requires additional electrical power. A solar array of 10,000 square feet is required and the orientation and power transfer turret must contain the additional feeders and control circuit wiring. Power distribution feeders for handling the growth requirements are built into the initial station power boom and core modules. The energy storage capability must also be increased. Two additional fuel cells and two electrolysis units are required.

These requirements were integrated into two additional station modules, a small core module and a solar array assembly to achieve the growth capability. The buildup sequence from initial to growth is shown in Figure 36, which begins with an initial station configuration that has two RAM's attached. The solar array is replaced and the growth core and station modules added. Initial station RAM's are relocated and an additional RAM attached to the growth core. The internal arrangement of facilities and equipment is the same for both of the additional station modules, SM-5 and SM-6 (Figure 37). ECLSS equipment, sized for a six-man crew (same as initial station modules), is located below deck in each module. Split-level crew quarters and personal hygiene installations are like the Type A modules of the initial station, SM-1 and SM-4.

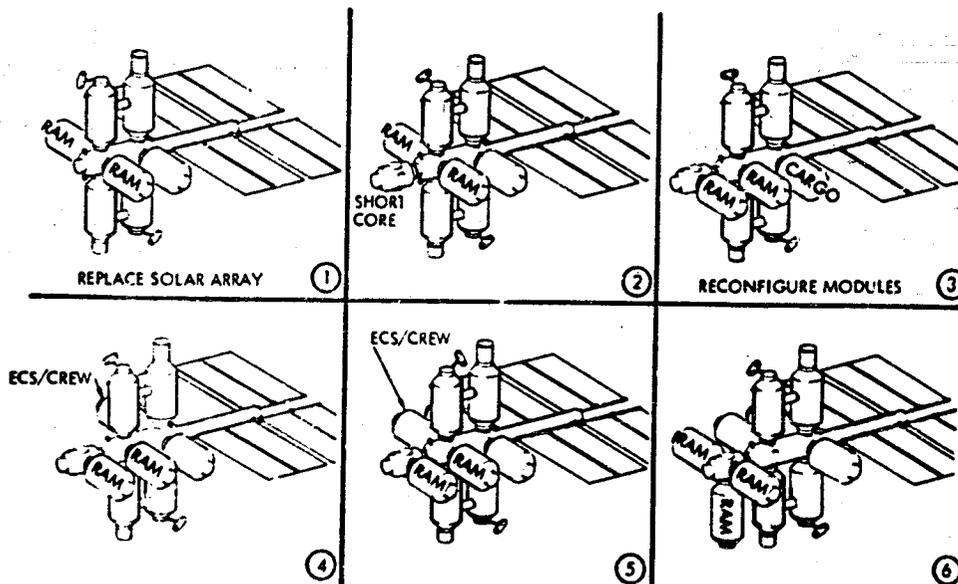


Figure 36. MSS Buildup Sequence (Growth Station)

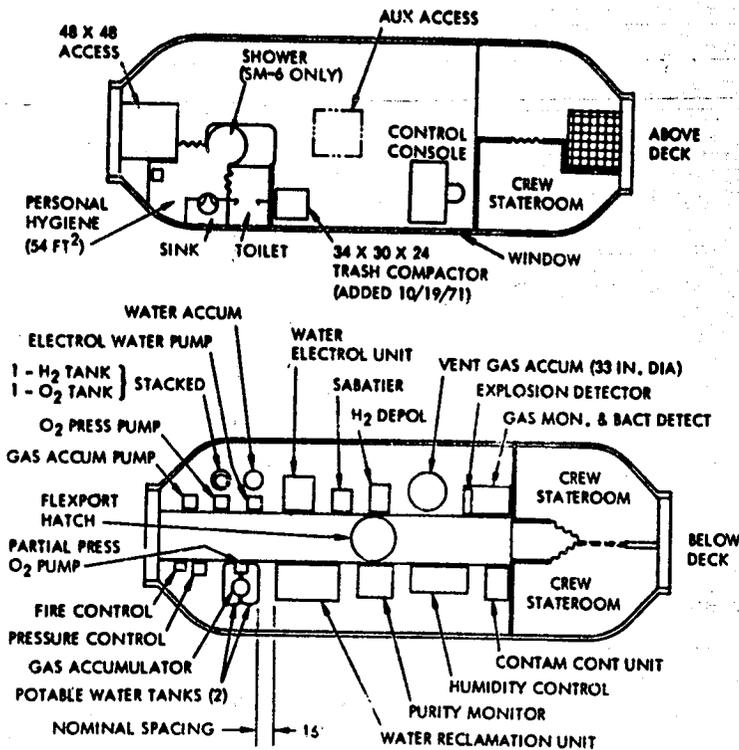


Figure 37. Station Modules 5 and 6 Arrangement

These additional station modules are berthed to the initial station Y plane (Figure 38) on the same side, one in V_1 , the other in V_2 . A flexport connects the two modules to form a passageway for a second way in or out of the two isolatable volumes. A small core module is added to the end port of the initial station core module to provide additional berthing ports for attached or detached RAM's. RCS engines are installed on the outboard end in the same plane as those on the initial core. Fuel cells, electrolysis assemblies, and power distribution equipment are installed in an on-orbit maintainable configuration. The berthing ports on the small growth core module are identical to those on the initial station and provide the same utility service at the interface.

DEVELOPMENT PLANNING

Development of subsystems for the modular space station will take maximum advantage of various developments presently under way at NASA or planned for the future. These include prototype hardware and technology developments for solar array, information management, ECLSS prototype, fuel cell, and thermal control (including heat pipes). In addition, the program goal of commonality (or at least similarity) of MSS subsystems

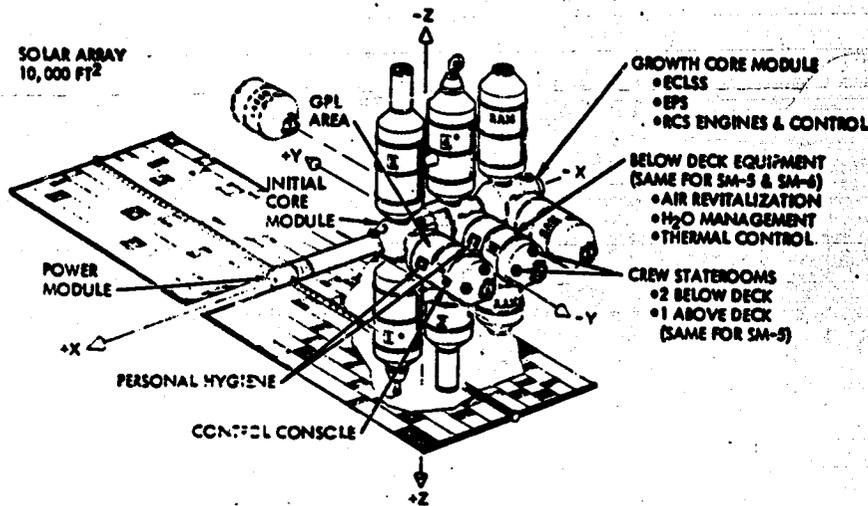


Figure 38. Growth Station External Configuration

with the shuttle subsystems, whenever possible, will greatly simplify the development problems for the MSS.

Development Approach

The various types of development tests, as well as the development requirements for each of the subsystems, are shown in Section 2 of SD 71-222, Modular Space Station Integrated Ground Operations. The development of each of the subsystems will include the development and verification of all software required to check out and operate that subsystem during all phases of its use. To facilitate the flow of information throughout each program phase and from lower level tests through spacecraft operations, a common data base (CDB) is needed. This CDB is a program-level approach to sources, format, and sinks of pertinent data and is used as a primary integration tool for all ground operations. The CDB imposes requirements for standard data format from all developers and users so that the various components may be integrated without reformatting these data. The CDB will use and store data from the initial specification values through development tests, acceptance, and orbital operations. Data compaction processes will be utilized to reduce the large quantities of data generated to a manageable and meaningful storage requirement.



Development Schedule

The goal of the development program is to verify or qualify the subsystems capability to meet the operational requirements. This will be accomplished by individual subsystem and software performance evaluations at the various environments individually specified. The final step in the qualification process is the integrated tests conducted in the compatibility assessment vehicle (CAV). Figure 39 shows that the qualification of the structure by means of the structural and dynamic test articles will be about 75 percent complete before the start of fabrication of the flight articles. Subsystem qualification, which includes the integration of the software in the CAV, will be essentially complete before the start of subsystems installation in the flight articles. These tests will be conducted initially with prototype subsystems and finally with flight-type subsystems installed.

Major Test Hardware

The development program will require several major test hardware configurations. Multiple use is made of many of these test articles to achieve MSS cost-avoidance goals. Figure 40 shows the structural and subsystem configurations for each module used in the development program. When more than one subsystem configuration is shown for a given module (such as Common Module 3 used in dynamic tests, compatibility assessment, and acceptance), the subsystems are updated to the new configuration between test sequences. The arabic numerals indicate the equivalent or portion of a complete subsystem installed (i. e., 0.75 = 75 percent of a complete flight subsystem).

Cost

Costs and funding spreads for the MSS earth orbital program are presented by project element (work breakdown structure) and program phase in Figure 41. These costs apply to the mission sequence plan previously shown and the program summary phasing schedule of Figure 42. A study guideline defined that the cost spreads cover design and development of the initial station and a period of five years after the growth space station is achieved. Utilizing this ground rule, the period of experiment cost spreads was defined to cut off all experiment operations after GFY 1992, and to omit all in-process costs for experiments and RAM's that are not operational by then. To provide a favorable funding profile, development and production of growth station modules, RAM's, and experiment equipment are delayed in the schedule until required by the mission sequence plan.

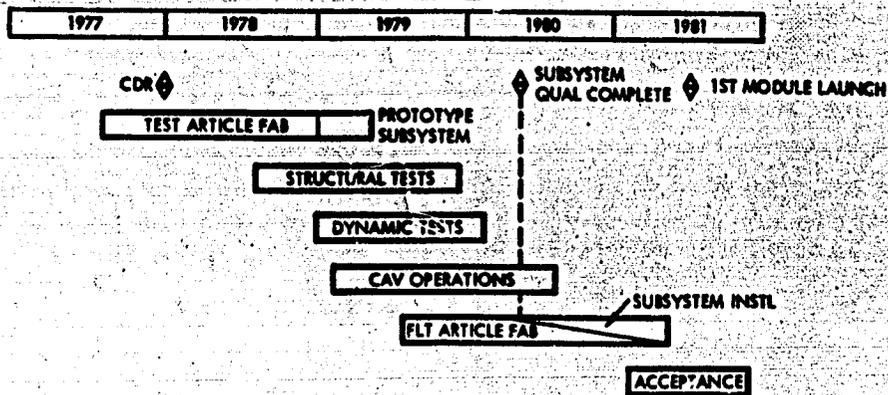
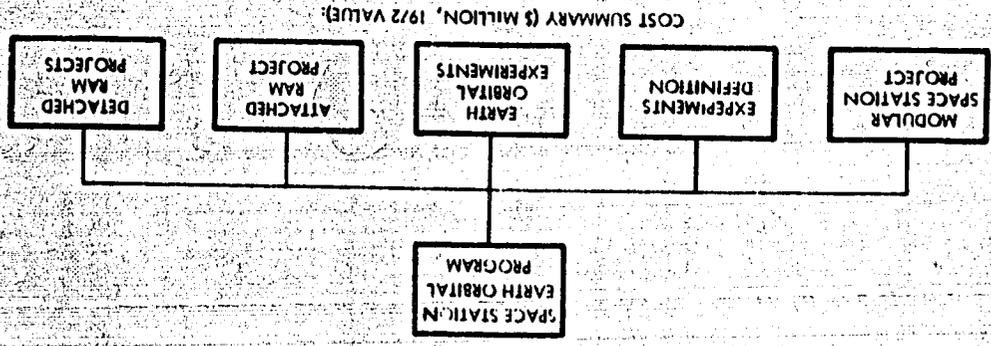


Figure 39. Qualification Schedule

ARTICLE	UTILIZATION																												
	STRUCTURAL TEST							DYNAMIC TEST							COMPATIBILITY ASSESSMENT							ACCEPTANCE AND MSV							
	STR	ISS	RCS	ECS	EPS	G&C	C&H	STR	ISS	RCS	ECS	EPS	G&C	C&H	STR	ISS	RCS	ECS	EPS	G&C	C&H	STR	ISS	RCS	ECS	LPS	G&C	C&H	
CORE 1																													
CORE 2								100	.75	.75	.75	.75	.75	0															
CORE 3	100	0	0	0	0	0	0																						
COMMON 1															100	A	SP	0	SPR	SP	0	0	0	SP	0	SPR	0	0	SP
COMMON 2	100	0	0	0	0	0	0								110	A	SP	SP	SPR	SP	0	0	0	SP	0	SPR	0	0	SP
COMMON 3								100	.75	0	.75	0	0	.75	120	A	SP	0	SPR	SP	0	0	0	SP	0	SPR	0	0	SP
POWER 1	100	0	0	0	0	0	0								110	A	SP	0	SPR	SP	0	0	0	0	0	0	0	0	0
POWER 2								100	0	0	15	.25	0	0															

- CODES
- A ENVIRONMENTAL SHIELD NIC
 - 0 PRIMARY STRUCTURE
 - S SIMULATED SUBSYSTEM
 - F FLIGHT-TYPE SUBSYSTEM
 - P PROTOTYPE SUBSYSTEM
 - (1) SECONDARY STRUCTURAL + BERTHING RING
 - (2) BERTHING ASSEMBLY ONLY
 - R RADIATORS NOT USED FOR HEAT REJECTION
 - ** PRIMARY SECONDARY BERTHING RING AND GPL FURNISHINGS
 - A SOLAR ARRAYS NOT INSTALLED

Figure 40. Major Test Hardware Configuration



PROJECT	DT&E	PRODUCTION	OPERATIONS	TOTAL
MODULAR SPACE STATION EXPERIMENT DEFINITION	114.6	-	-	114.6
EARTH ORBITAL EXPERIMENTS	1,863.5	176.3	561.9	2,601.7
ATTACHED RAM	158.4	49.9	0.4	208.7
DETACHED RAM PROJECTS	123.3	64.7	60.9	248.9
TOTAL, SSEO PROGRAM	\$3,853.7	\$708.9	\$984.4	\$5,547.0
NON-RECURRING				
RECURRING				

Figure 41. Summary of Program & Project Costs in Program Phase

The MSS product costs at the flight hardware subsystems' level and the non-flight hardware and support programmatic costs are summarized in Table 5. The program costs and funding spread are shown in Figure 43.

Table 5. MSS Project Costs

WBS Elements		DT&E	Production	Operations	Total
Product Costs					
Structures & mechanisms	255	267	70	35	290
ECISS	267	70	35	337	337
EPS	145	127	10	292	292
GFC	61	10	4	71	71
RCS	25	4	29	253	253
ISS	191	42	8	239	239
Crew habitability	45	8	53	106	106
Subsystem installation	-	27	-	27	27
Cargo module refurbishment and checkout	-	-	53	53	53
Total product costs	1,009	343	53	1,405	1,405
Programmatic costs	585	75	308	968	968
Total space station project costs	1,594	418	361	2,373	2,373

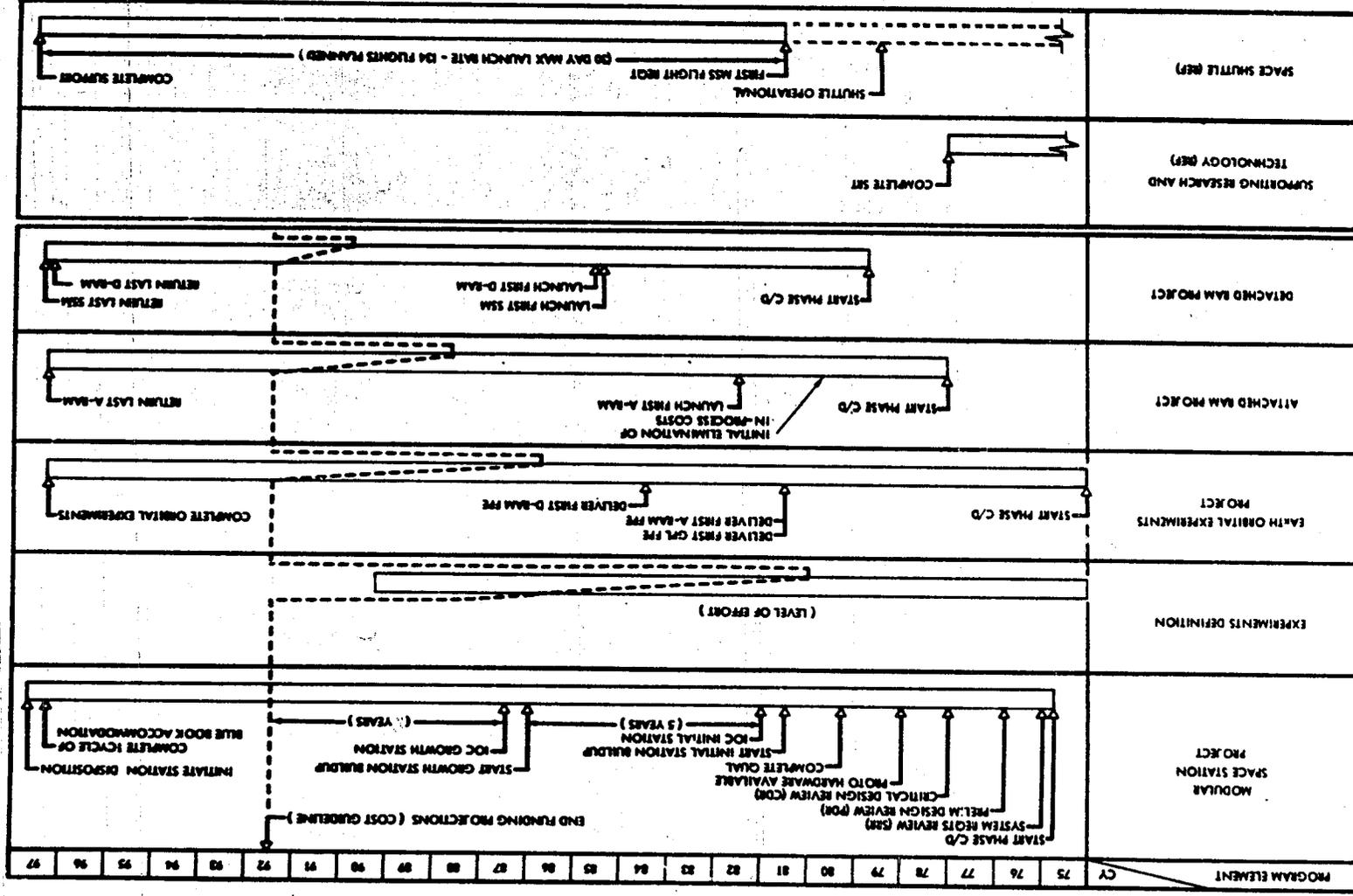
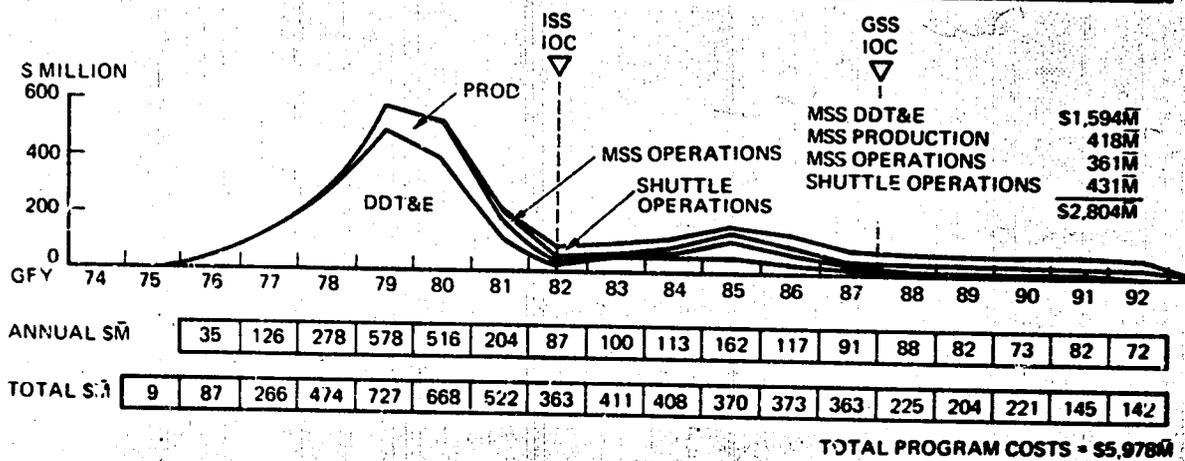
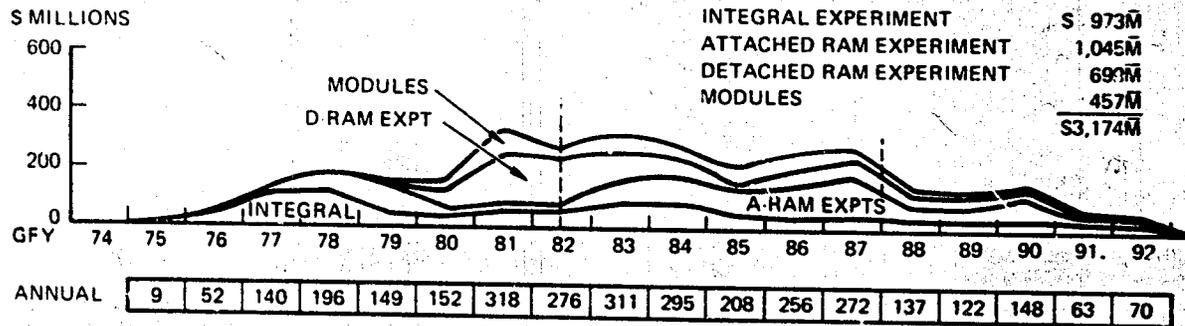


Figure 42. Program Summary Phasing Schedule



Figur. 43. Program Costs and Funding Spread

SORTIE MISSION ANALYSIS

An analysis of sortie missions has been conducted which defines a modular space station-oriented experiment program to be flown by the shuttle from the time of the shuttle's first mated orbital flight (April 1978) to the initial modular space station's IOC (third quarter, 1981). During this period, about 45 shuttle flights are scheduled. * For the purpose of this analysis, it was assumed that all of these flights would be available for the sortie experiment program.

Factors considered in this analysis included the amount of shuttle dependency involved, potential sortie mission module/space station module commonality, shuttle/station/sortie module subsystem commonality, funding requirements, and experiment returns.

The major issues centered around the types of experiments that are best suited for both 7- and 30-day sortie operations, their assembly into packages and payloads, crew skills and number of crewmen required, the orbit parameters, and the shuttle's capability to fly the desired missions.

The objectives of this analysis were to define an experiment program that would represent a practical program flow from the first sortie flight to the initial station IOC, and to establish if commonality existed between sortie mission modules and subsystems and station modules and subsystems and its value toward development of the station.

SORTIE MISSION DEFINITION

The sortie analysis included three modes of operation: Mode I is a 7-day mission wherein the experiments are remotely controlled from the flight compartment. Mode II also is a 7-day mission but manned access to the experiment payload has been added. Mode III is a 30-day mission in which the payload also is accessible to the crew. In all three modes the payload is dependent upon the shuttle for its primary support. This support is provided in two ways: by the basic shuttle subsystems or by augmenting the capabilities of these subsystems as required. This augmentation is discussed later in this document. For the 30-day mission, the shuttle's own subsystems (EPS and ECLSS) also must be augmented, as their baseline capability is only seven days.

Two ways were selected to accommodate the sortie payloads for the three mission modes described previously. For the remotely controlled

*Shuttle Traffic Model, SD 70-600-23

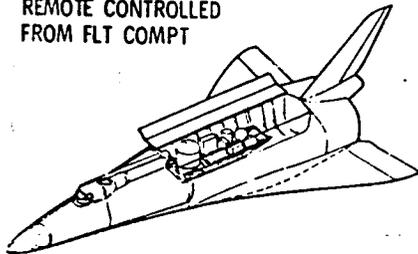
experiments, the payload was pallet-mounted in the payload bay of the shuttle and all the necessary controls and displays were located in the flight compartment. For those experiments requiring crew access, the payload was located in the payload bay and access accomplished through the interface tunnel from the flight compartment. An alternate means to accomplish crew access was to move the payload from the payload bay to the shuttle's berthing port by the manipulator. In this position, access is available through the shuttle's airlock. Figure 44 illustrates these accommodations.

SORTIE EXPERIMENT PAYLOADS

The experiments selection was based on an analysis of the 1971 Blue Book for experiments that met level 1 criteria (i. e., a precursor to the station, providing early return during the shuttle-station gap period and having operating time commensurate with the 7- and 30-day mission times).

The selection of equipment that supports the selected experiments was based on equipment costs, complexity, and commonality with other pieces of equipment.

- PALLET - MOUNTED
REMOTE CONTROLLED
FROM FLT COMPT



- CREW ACCESSIBLE
PAYLOAD BAY OR AIRLOCK

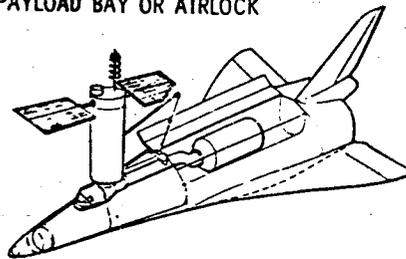


Figure 44. Shuttle Payload Accommodations

The experiment payloads were developed by grouping experiments that were compatible relative to a set of discrete mission constraints, crew skill requirements, and shuttle volume and weight considerations. Tables 6 and 7 illustrate the grouping of the experiment packages into 7- and 30-day manned payloads, respectively.

PAYLOAD ACCOMMODATION

An analysis of the experiment accommodation requirements for the 17 sortie payloads revealed those which required airlocks and/or an unpressurized pallet or a pressurized module with manned entry capability.

For the seven-day missions, four payloads require airlocks of pallets while the remaining two need a pressurized module. For those requiring an airlock, considerations were given to using the MSS airlock or the shuttle orbiter's airlock. The MSS airlock was selected based on complexity and interfaces with the orbiter.

For the 30-day missions, all 11 payloads require a pressurized module for extra living accommodations over that provided by the orbiter. In eight cases, a pressurized module also is needed for the experiments while the remaining three utilize a pallet, an airlock, and a combination pallet-airlock. Figures 45 and 46 illustrate these accommodations.

COMMONALITY AND COST ANALYSIS

Analyses were conducted to determine the level of commonality among sortie and station modules and subsystems equipment, and the resulting dollar benefit to the MSS development.

To achieve commonality for module configuration, the MSS universal structure concept was selected as illustrated in Figure 47. As a result of the sortie payload analysis, three module configuration lengths would be required. Two module lengths could satisfy these requirements by mating the 10- and 20-foot modules for the third module length. The 20-foot module is a derivative of the MSS cargo module. The MSS airlock concept will be used where an airlock is required.

The results of the subsystem commonality analysis are illustrated by the bar graphs in Figure 48. As an example, the video recorder from the information subsystem has five sortie payloads that have 80 percent commonality, and four have 30 percent commonality to the MSS. Of these sortie payloads, nine have 30 percent and five have 80 percent commonality among themselves. The delta percentage differences exist because of additional equipment or physical characteristics differences.

Table 6. 7-Day Sortie Mission Payloads

PAYLOAD NO.	EXPERIMENT PACKAGE	INCL (DEG)	ALT (N MI)	CREW SIZE
7M-1	EARTH OBS CONTAMINATION TECHNOLOGY	55	100- 300	3
7M-2	CONTAMINATION TECHNOLOGY SPACE PHYSICS	90	80x100/500	2
7M-3	EARTH OBS ADVANCED S/C SYSTEMS TESTS CONTAMINATION TECHNOLOGY	55	100	2
7M-4	MATERIALS SCIENCE	28-1/2	200	2
7M-5	PLANT GROWTH CELLS & TISSUES EVA	28-1/2	100	3
7M-6	PLASMA PHYSICS	55	270	2

Table 7. 30-Day Sortie Mission Payloads

PAYLOAD NO.	EXPERIMENT PACKAGE	INCL (DEG)	ALT (N MI)	CREW SIZE
30M-1	EARTH OBS CONTAMINATION TECHNOLOGY	55	100	2
30M-2	SPACE PHYSICS PHYSICS & CHEM	28-1/2	200	2
30M-3	FLUID MGMT	28-1/2	300	2
30M-4	MEDICAL RESEARCH BIO-SCIENCE LIFE SUPPORT MAN SYSTEMS	28-1/2	100	3
30M-5	X-RAY STELLAR ASTRONOMY	28-1/2	400	2
30M-6	ADVANCED SOLAR ASTRONOMY	SUN SYNCH	220	2
30M-7	INTERMEDIATE U-V TELESCOPE	28-1/2	250	2
30M-8	HIGH ENERGY STELLAR ASTRONOMY	28-1/2	400	2
30M-9	INFRA-RED ASTRONOMY	55	270	2
30M-10	COSMIC RAY PHYSICS	28-1/2	200	2
30M-11	COMMUNICATIONS	55	150	2

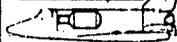
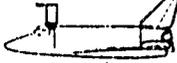
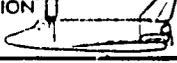
PAYLOAD	EXPERIMENT PACKAGE	TITLE	ACCOMMODATIONS		
			MODULE	AIRLOCK	PALLET
1	MS-III	MATERIALS SCIENCE			
2	LS3-II LS4-II T3-I	PLANT GROWTH CELLS & TISSUES ASTRONAUT MANEUVERING UNIT			
3	ES1-II T4-I T1-I	LAND USE MAPPING ADVANCED SPACECRAFT SYSTEMS TESTS SKY BACKGROUND BRIGHTNESS			
4	ES1-III T1-I	AIR & WATER POLLUTION SKY BACKGROUND BRIGHTNESS			
5	P1-I T1-I	ATMOSPHERIC/MAGNETOSPHERIC SCIENCES SKY BACKGROUND BRIGHTNESS		AIRLOCK AS PALLET	
6	P2-I P2-II	PLASMA WAKE PLASMA RESONANCES/HARMONICS	MAINT/ CALIBRATION ONLY		

Figure 45. Seven-Day Mission Payload Accommodations

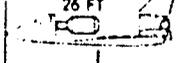
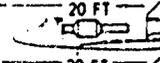
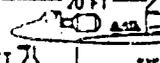
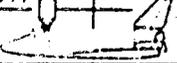
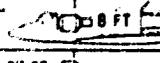
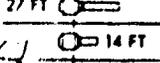
PAYLOAD	EXPERIMENT PACKAGE	TITLE	ACCOMMODATION		
			MODULE	MOD/ AIRLOCK	MOD/ PALLET
1	LS1-I LS4-I LS5-I LS6-I LS7-II	BIOMEDICAL RESEARCH ROLE OF GRAVITY IN LIFE PROCESSES LIFE SUPPORT SYSTEMS DEVELOPMENT PERFORMANCE CAPABILITY ASSESSMENT	 26 FT		
2	P1-II P4-I	COMETARY PHYSICS MOLECULAR PHYSICS	AIRLOCK AS PALLET	 20 FT	
3	T2-I T2-II T2-III	LIQUID/VAPOR INTERFACE STABILITY BOILING HEAT TRANSFER CAPILLARY STUDIES		 20 FT	
4	ES1-I T1-II	METEOROLOGY/ATMOSPHERIC SCIENCES REAL TIME CONTAMINATION		 20 FT	
5	A1-I	HIGH-RESOLUTION X-RAY TELESCOPE		TELESOPES	 45 FT
6	A3-I	PHOTOHELIOGRAPH		 40 FT	
7	A4-I	NARROW-FIELD UV TELESCOPE		 38 FT	
8	A5-I	LOW-ENERGY X-RAY TELESCOPE		 27 FT	
9	A6-I	DETECTOR ARRAY SCANNING	 25 FT LAB	 14 FT	
10	P3-I	COSMIC RAY NUCLEI CHARGE/ENERGY SPECTRA			
11	C/N1-II C/N1-III	MILLIMETER WAVE COMM SYSTEM/PROP- AGATION SURVEILLANCE/SEARCH/RESCUE SYSTEMS			 20 FT

Figure 46. Thirty-Day Mission Payload Accommodations

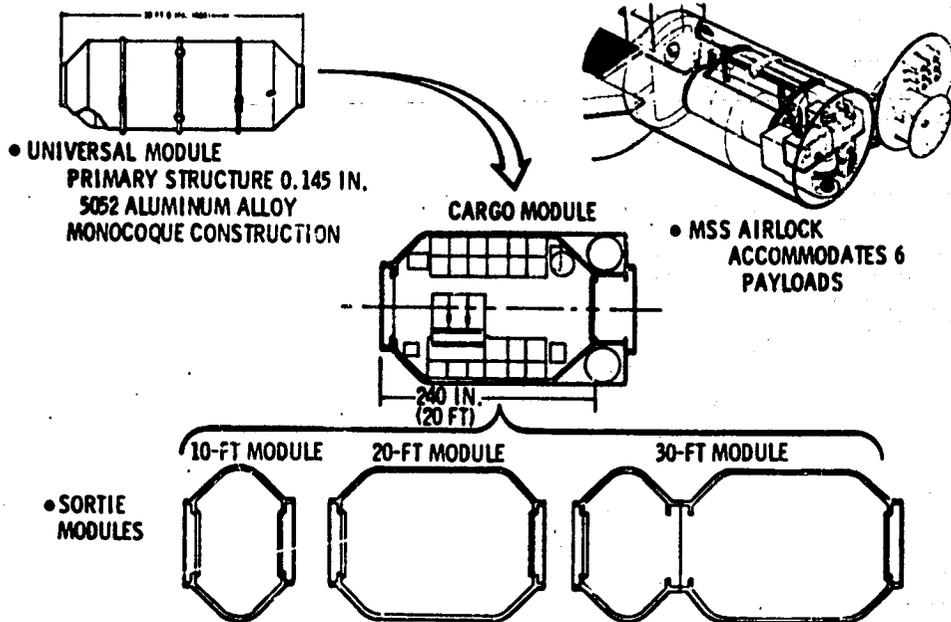


Figure 47. Structure Concept Selection

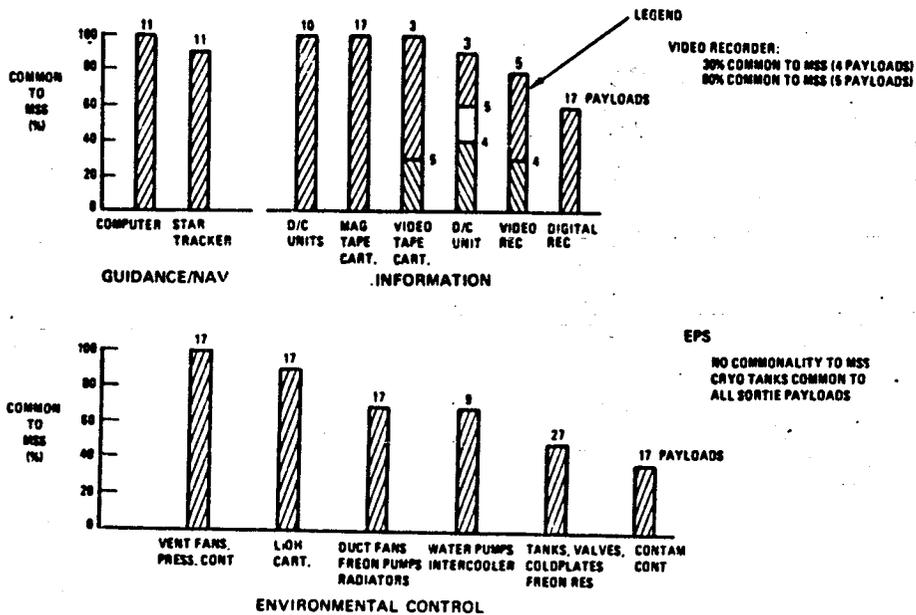


Figure 48. Subsystems Commonality

The sortie payload cost analysis was accomplished in three steps: (1) determination of the development cost, assuming that each individual payload was developed separately; (2) recognizing the commonality between payloads, determination of the development cost when the costs of payload-common items were shared among payloads; and (3) based on commonality percentage to the MSS, the dollar benefit to the MSS development was determined.

The results show that approximately a 60 percent savings is accomplished by sharing cost among payloads as illustrated in Table 8. Approximately a 4 percent cost savings can be contributed to the initial MSS development cost. Intangible savings to the MSS not expressed in dollar value are identified as component reliability data, experiment procedures, operational experience, and maintenance procedures.

Table 8. Development Cost Analysis Results

Item	Independent Development \$M (1972)	Shared Development (\$M)	Savings to MSS (\$M)
Structure	770	140	28
ECLSS	370	120	27
EPS	120	25	--
G&C	305	235	5
Information	120	30	10
Crew/habitability	115	20	7
Total	1800	570	77

SORTIE LABORATORY

An alternative approach to the accommodation of sortie payloads would be to provide a family of general-purpose laboratories. With this concept, each sortie GPL would support a group of related disciplines and would contain, as an integral part of the module, laboratory and experiment equipment. The intent would be to minimize the amount of equipment required from the investigator. The sortie GPL's would be designed to exploit the reusability made possible by the shuttle. That is, they would be adaptable to a wide range of missions and users with a minimum of reconfiguration. In addition, use would be made of existing ground and aircraft-based laboratory equipment (microscopes, cameras, spectrometers, multimeters, etc.) where practical, to minimize costs.

Table 9 shows two possible approaches considered for grouping disciplines into sortie GPL's. The first is a phenomenon-oriented family which groups disciplines into sortie GPL's according to the particular aspect of the space environment associated with their objective. The second is a purpose-oriented family which groups disciplines into sortie GPL's according to the general nature of their objective.

Table 9. Sortie GPL Approaches

Lab Type Discipline	Phenomenon-Oriented Approach			Purpose-Oriented Approach		
	Earth Remote Sensing	Space Remote Sensing	Zero-Gravity, Vacuum	Application	Technology	Science
Astronomy		X				X
Physics		X				X
Earth observations	X			X		
Communications/ Navigation	X				X	
Material sciences			X	X		
Technology	X	X	X		X	
Life Sciences			X	X		

Based on NR's studies to date, the purpose-oriented approach appears the most desirable for a family of sortie GPL's or sortie labs.

For this study, an application laboratory was selected for conceptual definition. Figure 49 depicts the application laboratory concept and points out the location of the various pieces of laboratory equipment associated with earth observations, material, and life sciences. The laboratory is 20 feet long excluding the 12-1/2 foot airlock. The upper floor is dedicated to the earth observation and life science laboratories and the lower floor is dedicated to material science. The laboratory is fixed in the shuttle payload bay with the necessary sensor exposure obtained through the open payload bay doors. For the earth observation telescope, outward looking is obtained by employing a right-angle aperture.

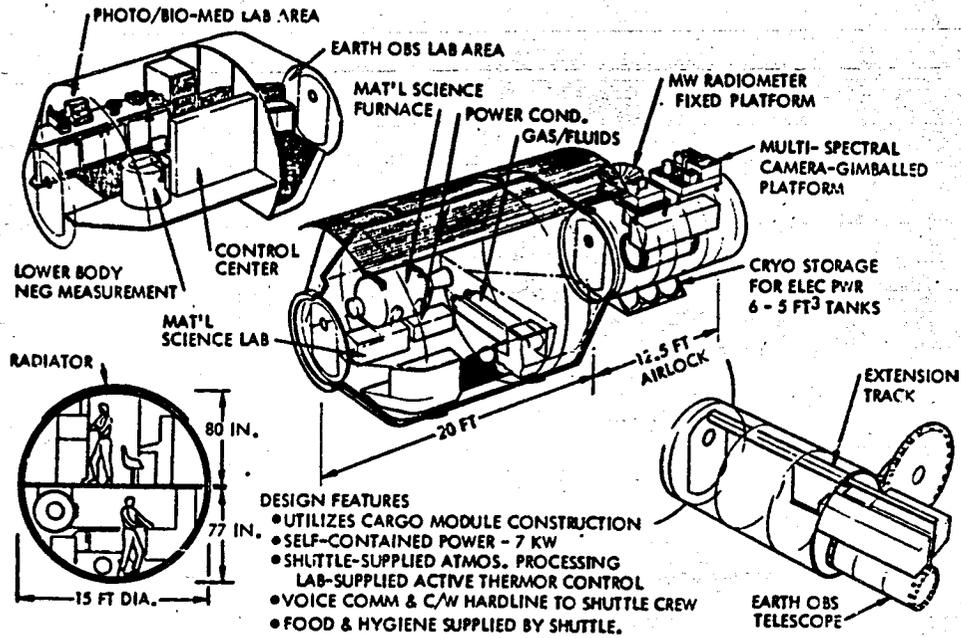


Figure 49. Applications-Type Sortie Laboratory

REDUCED PAYLOADS SIZE IMPACT STUDY

The reduced payload size impact study identified the modular space station effects resulting from a reduction in diameter and length of individual modules. These effects are defined for 12- by 40-foot, 14- by 40-foot, and 12- by 58-foot modules and associated shuttle payload bay sizes. The configuration used for comparison and identification of impacts was the preliminary design Phase B 14-foot module configuration.

The internal accommodations for crew habitability, station operation, and all general-purpose laboratory facilities were required to be the same as the Phase B station for all reduced payload size options. Thus, modular stations assembled from all of the options will have essentially similar experiment capability except for configurational impacts.

Figure 50 compares the concept 1 growth configuration and the 14-foot Phase B growth configuration. The concept 1 configuration is composed of six station modules and two 40-foot core modules for the initial station and eight station modules and two 40-foot core modules for the growth station. The concept 1 initial station exceeds the length of the 14-foot Phase B initial station by 40 percent and the growth station by 22 percent, with appropriate increases in moments of inertia and control penalties. The reduction in module diameter and the increased configuration length contribute to a general overall reduction in structural stiffness and dynamic characteristics.

Figure 51 compares the 14-foot Phase B and the reduced-diameter concept 1 and concept 3 configurations. The 14- by 40-foot (concept 2) reduced length configuration is not shown since it is identical to the 14-foot Phase B configuration.

The 14-foot Phase B initial space station configuration is characterized by a balanced split of station modules between volume 1 (V_1) and volume 2 (V_2) with a minimum of growth scars. The concept 1 space station configuration requires two additional station modules to provide the equivalent accommodations of the 14-foot Phase B configuration. These additional station modules result in a 2 by 4 split between V_1 and V_2 . An additional core is required by the initial station, resulting in growth scars of additional berthing ports and associated increases in complexity. The concept 3 space station configuration requires five station modules with modules less than 49 feet in length. This configuration also dictates an uneven 2 by 3 split between V_1 and V_2 . The growth scar of this configuration is further increased over the initial station because the side berthing ports cannot be totally utilized.

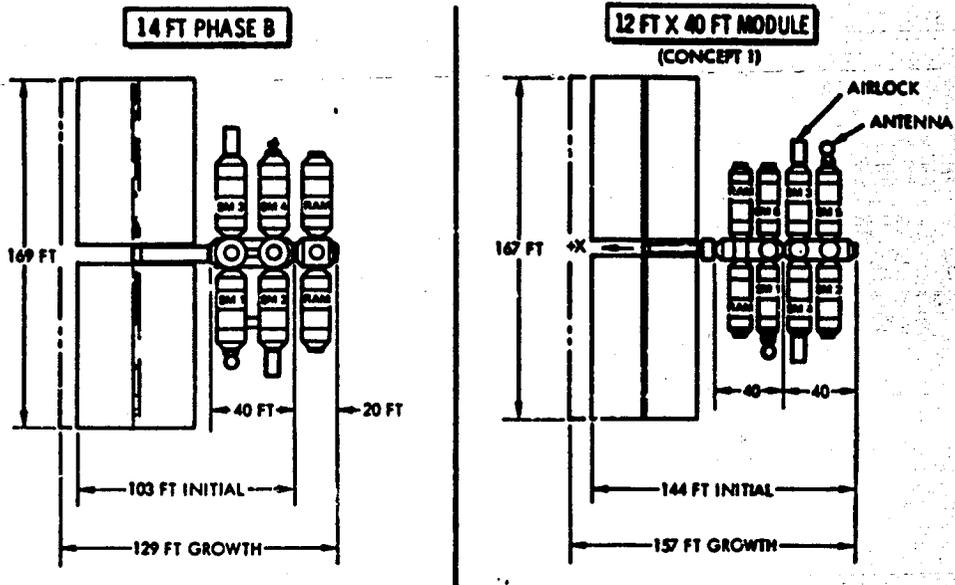


Figure 50. Reduced Payload Size Concept Dimensions

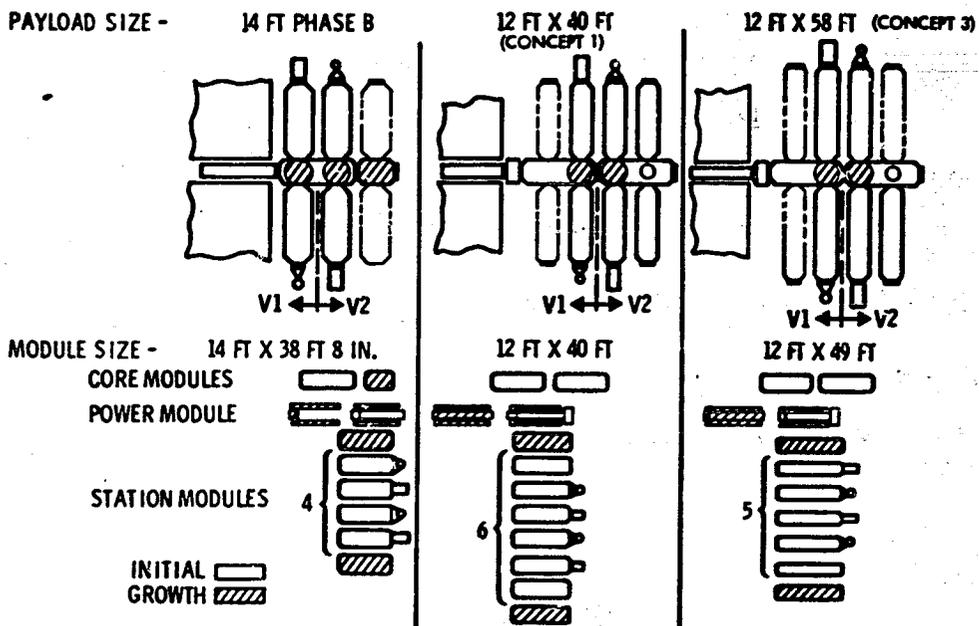


Figure 51. Configuration Comparison



The 14-foot Phase B space station has been optimized for an initial station where the concept 1 and concept 3 space stations tend to be optimized to the growth station. This is driven by the increased number of station modules requiring an additional core module for the initial station.

The concept 1 and concept 3 configuration core modules are much more complex because of the recessed ports and the reduced interface volume at the berthing ports for distribution of basic subsystem service and utilities from one module to another. The concept 1 and concept 3 station modules are single-level internal arrangements driven by the reduced diameter. The single-level arrangement generally expands the traffic patterns, compromises the location of particular accommodations, and generally contributes to a substantial increase in machinery noise in the station living and operating areas.

Table 10 summarizes the delta cost effects for the concept 1 initial space station program. The cost changes attributable to a 12-foot-diameter station versus a 14-foot Phase B station were analyzed at the subsystem (WBS level 5) level, using 14-foot Phase B cost estimating relationships (CER's). The design and development and flight hardware costs derived amount to slightly more than \$70 million for the initial MSS. The estimate of major test hardware (MTH) increased in cost about \$40 million. Based on initial cost estimates for the baseline 14-foot Phase B configuration, the concept 1 space station would cost approximately 12.5 percent more than the 14-foot Phase B configuration.

The study results conclude that modular space stations configured with 12-foot diameter and reduced length modules do meet requirements. Problems unique to these configurations appear to be solvable. As driven by the diameter reduction and increase in number of modules, program costs are increased. The further increase in complexity is a prime issue and concern that resulted from the study. Because of this general increase in complexity of the MSS concept, it is recommended that the reduced diameter modules be avoided.



Table 10. Summary of Cost Changes (Initial Station)

	Dry Weight Increase (lb)	Increase in Cost (\$ Million, 1971 Value)		
		Design and Development	Flight Hardware	Delta
Structures & Mechanisms	17,675	\$29.1	\$ 9.2	\$ 38.3
ECLSS	3,230	10.7	4.3	15.0
EPS	638	3.2	2.1	5.3
G&C	173	1.1	0.5	1.6
RCS	60	0.9	1.0	1.9
ISS	596	6.3	3.1	9.4
Total	22,372	\$51.3	\$20.2	\$ 71.5
Major test hardware				\$ 40.5
Increased integration complexity				13.0
Total increase above cost items				\$125.0
Support & floating item costs at approximately 100%				125.0
Total project cost increase				\$250.0
Approximate increase over 14-ft station				12.5%

INFORMATION MANAGEMENT ADVANCED DEVELOPMENT

A special set of tasks (SOW 4. 2) was included in the Phase B extension study to provide advanced development of selected information subsystem concepts. The three objectives were (1) to provide to NASA-MSC working breadboard subassemblies for evaluation of the MSS information subsystem concepts, performance, and integration constraints; (2) to achieve more industry participation in the MSS program; and (3) to contribute to the MSS Phase B preliminary design efforts. Three major areas were selected: a brassboard RF communications terminal subassembly consisting of the K-band electronics to be installed on the directive antenna; a breadboard of the data acquisition and control subassembly consisting of a common 10 mbps digital data bus configured as for installation in the MSS; and preliminary performance specifications for the data processing assembly and the computer program assembly so that an engineering evaluation model of the MSS multi-processor computer could be procured by NASA at a later date.

The listing in the next paragraph shows how the tasks were divided into subtasks and assigned. The subcontractors selected were International Telephone and Telegraph (ITT), Nutley, N. J.; Systems Development Corporation (SDC), Santa Monica, Calif. Intermetrics (INTER), Cambridge, Mass.; General Electric Corporation (GE), Valley Forge, PA.; Autonetics (AN) Division, NR, Anaheim, Calif. The Space Division (SD), NR, provided technical guidance and integration as well as several direct subtasks.

RF Communications Terminal

- SD/MSC - Determine BB performance requirements
- SD/ITT/MSC - Identify GFE/make/buy items
- ITT - Develop BB assemblies
- SD/ITT/MSC - Install/demonstrate at MSC

Data Acquisition/Control Subassembly

- SD - Shuttle/station commonality
- ITT - Bus design notebook
- SD/AN/ITT/MSC - Determine DACS performance/interface requirements
- ITT - Develop cabling configuration
- AN - Develop data bus controller
- MSC - Provide RACU and test processor
- AN - Integrate assembly
- SD/MSC - Install/demonstrate at MSC



Data Processor Assembly Specifications

- SD - Define ISS/subsystems interactions
- SD/SDC - Develop information flow charts
- SDC - Simulate ISS throughout
- INTER - Internal DPA traffic flow and memory division studies
- SD/AN/SDC/MSC - Select evaluation model configuration
- SD/AN - E. E. model performance requirements and development plan
- AN - EEM supervisor specification

Computer Program Specifications

- SDC - Recommend programming standards
- SDC - Develop software system specification tree
- SDC - Prepare configuration control plan
- SDC - Resource allocation program requirements

Bulk Storage Devices

- GE - Technology assessment
- GE - Prepare prototype performance requirements and development plan

DATA ACQUISITION AND CONTROL

One of the primary objectives of the information management advanced development task is the delivery of a data acquisition and control subassembly (DACS) breadboard. The task also includes the analyses of redundancy concepts and the development of parametric data for use in designing data buses for a family of space vehicles.

The DACS breadboard will consist of a data bus breadboard, a data bus control unit (DBCUC) breadboard, and one or more remote acquisition and control unit (RACUC) breadboards. The data bus breadboard and the DBCUC breadboard will be delivered at the end of the effort; the RACUC breadboards will be Government-furnished equipment. Figure 52 is a block diagram of a dual redundant test setup of the DACS breadboard; it shows, inside the dashed line, the complement of breadboards and equipment to be delivered under this contract.

COMMUNICATIONS TERMINAL

The principal goal of this task is to produce a brassboard piece of hardware that demonstrates the concept of an MSS external communication

The other ADT tasks are listed in Table II, along with a brief summary of the task results. These tasks represent that part of the ADT study that does not pertain to the data acquisition and control subsystem or the communications terminal breadboard (CTB) tasks which were discussed in the preceding two subsections.

OTHER ADT TASKS

terminal for the MSS/TDRS link. Emphasis is placed on the RF systems integration concept for a combined transmitter/receiver package to be mounted on the directive antenna in the space environment. Choice of the TDRS as the relay satellite defined the use of K-band (13.4 to 15.35 GHz) as the operational frequency of the breadboard.

Figure 52. Dual Redundant DACS Breadboard

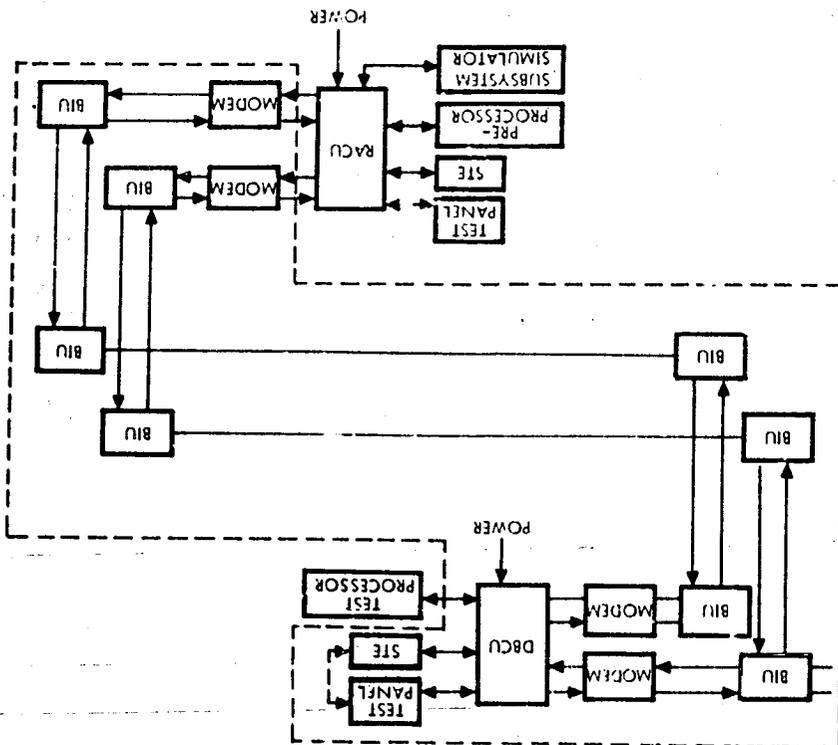


Table 11. Advanced Development Tasks

Task Name	Task Results
Shuttle/EOSS commonality	Investigated the degree of commonality between the MSS/shuttle ISS hardware and requirements. Little commonality was found.
Parametric evaluation/ subsystem input/output interface	Define DPA computation requirements and interfaces with other sub-systems used as basic requirements for both Phase B and ADT studies.
DPA configuration	Defined baseline DPA configuration early in ADT study. Updated baseline to reach Phase B configuration. Final configuration due January 1972.
Supervisory specification	Preliminary CP supervisor program requirements have been specified. Final report due January 1972.
DPA performance requirements	Preliminary DPA processors performance requirements were developed to support Phase B study. Task complete May 1972.
DMS EEM processor development plan	Task scheduled to start January 1972. Complete in May 1972.
DPA redundancy concepts	Established the impact of the "MSS failure criteria" on the DPA design and recommended a redundant configuration.
Initial-bulk storage development plan - initial station	Task started in October 1971. Completion due in February 1972.
DPA information flow diagrams	Structured the DPA software system and defined the data that flow between software modules, in preparation for throughput simulation analysis.
DPA throughput and authority analysis	Simulated the DPA configuration and measured throughput for worst case workload. Established that selected configuration is viable.
DPA configuration selection	Supported selection of the DPA configuration by analyzing the throughput simulations.
Standards and conventions manual	Identified salient MSS software problem areas and established philosophies to be followed when dealing with them.
Computer program specification tree	Identified the MSS computer program, the specifications required to define them, and the related documentation for each one.
Computer program development plan	Task started in November 1971. A preliminary software development plan has been completed.
DPA resource allocation	Task scheduled to start January 1972.
DPA internal flow and traffic pattern	Refined the factors that influence multiprocessor designs. Developed a multiprocessor design handbook that was used in the central processor definition activities.
Central processor operational analysis	Investigated the impact of software, failure tolerance, expandability, flexibility, and crew interface on the central processor hardware design. Recommended central processor design that implemented these factors.
Mass memory parametric data	Studied the mass memory technologies available for the DPA and did a comparative evaluation based on parametric quantities.
Central processor memory organization and internal bus design	Preliminary definition of the CP memory division, module sizes, and speeds, along with the bus design to communicate between them. Task complete January 1972.



PROGRAM OPTIONS

At the request of NASA, a set of program-level alternatives to the MSS Phase B program was investigated. Key differences from study guidelines were:

- Reduction in the experiment program
- Deferral of costly experiment equipment even if it creates an unbalanced experiment program
- A \$100-million per year limit on experiment equipment expenditures
- Initial space station only — no growth provisions
- Five years of operation only

This created a set of four alternative program options. In addition to these, a corresponding set of four options was created that incorporated an evolutionary sortie-to-station program. Finally, a separate program (Option 10) that combines the best features of the other options, but also adds additional program peak and total cost reduction changes, was developed. The eight options mentioned are shown in Figure 53, together with a reference program that accomplishes the entire Blue Book and baseline program described in this report. Option 10 will be described later in this section.

PROGRAM CONTENT

The content of each of the program options is shown in Table 12. Within each discipline, the FPE and the level of accommodation are presented for both the basic four options and their corresponding sortie-to-station evolution program. Levels II and III apply to programs 2 through 5; addition of experiments at level I and corresponding shuttle sortie flights convert the programs to numbers 6 through 9.

The programs are summarized in Table 13 in terms of the number of experiment disciplines represented, experiment equipment groups, shuttle flights, experiment equipment modules, and support sections. Also, the total experiment crew time and experiment duration are defined. The number of shuttle missions required to support the program depends primarily on the program duration varying from 28 for the limited-funding program to 131 for the longer-duration, balanced program.

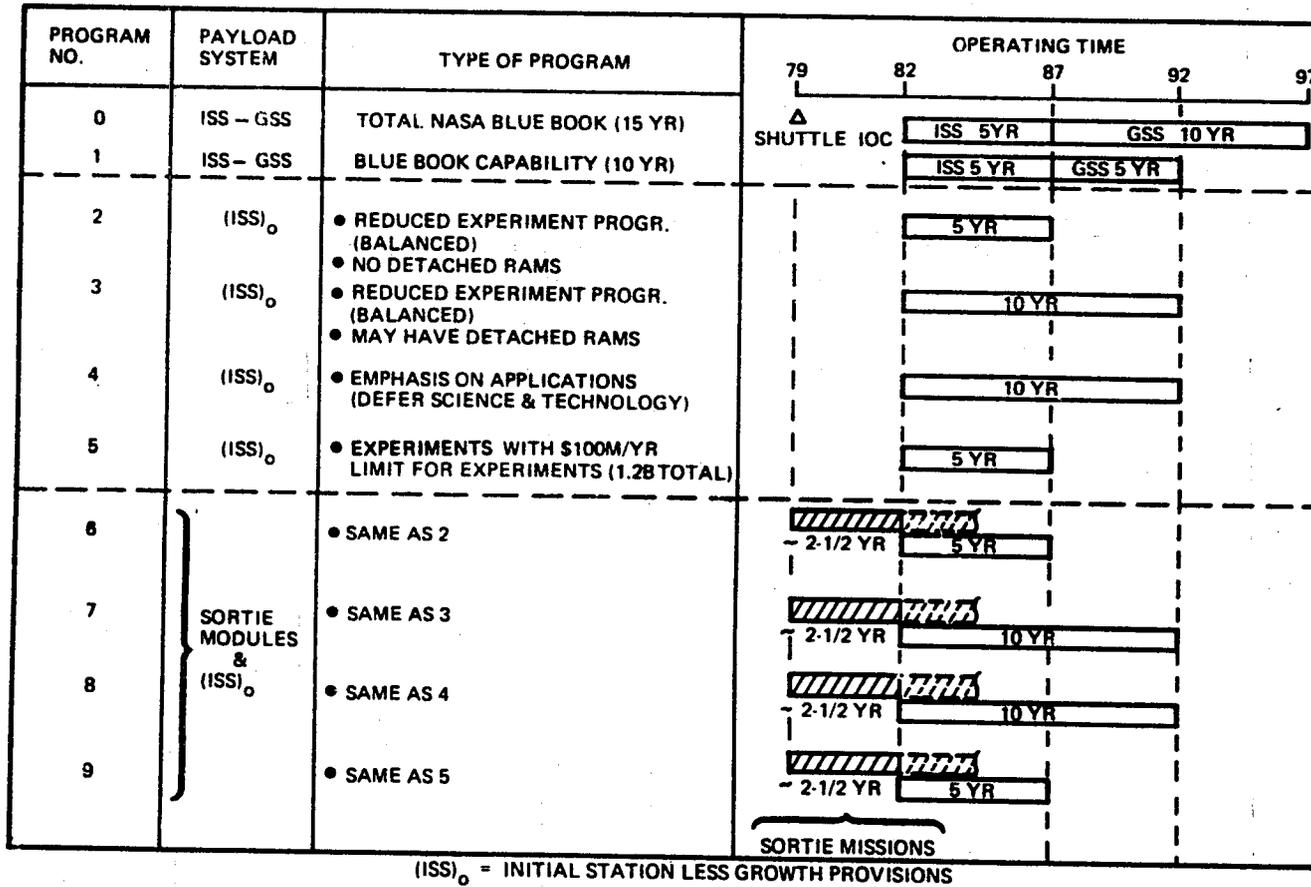


Figure 53. Alternate Program Options

Table 12. Program Comparison

DISCIPLINE	NO.	FPE TITLE	LEVEL	0 REFERENCE			2 SORTIE + BALANCED (2)			3 SORTIE + BALANCED (3)			4 SORTIE + APPLICATION (4)			5 SORTIE LIMITED FUND (5)		
				I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
ASTRONOMY	A1	X-RAY STELLAR																
	A2	ADVANCED STELLAR																
	A3	ADVANCED SOLAR																
	A4	INTER SIZE UV TELESCOPE																
	A5 A6	HIGH ENERGY STELLAR IN ASTRONOMY																
PHYSICS	P1	SPACE PHYSICS RESEARCH FAC																
	P2	PLASMA PHYSICS & ENV PERTS																
	P3	COSMIC RAY FAC																
	P4	PHYSICS & CHEMISTRY FAC																
EARTH OBS	ES1	EARTH OBSERVATIONS FAC																
COMM/NAV	CN1	COMMUNICATIONS/NAVIGATION FAC																
MATERIALS SCI	MS1	MATERIALS SCIENCE/MFG FAC																
TECHNOLOGY	T1	CONTAMINATION MEASUREMENTS																
	T2	FLUID MANAGEMENT																
	T3	EXTRA VEHICULAR ACTIVITY																
	T4	ADVANCED S/C SYSTEMS TEST																
	T5	TELEOPERATIONS																
LIFE SCIENCES	LS1	MEDICAL RESEARCH FAC																
	LS2	VERTEBRATE RESEARCH FAC																
	LS3	PLANT RESEARCH FAC																
	LS4	CELLS & TISSUE RESEARCH FAC																
	LS5	INVERTEBRATE RESEARCH FAC																
	LS6	LIFE SUPPORT & PROTECTIVE SYS																
	LS7	MAN-SYSTEM INTEGRATION																
EXPERIMENT EQUIPMENT GROUPS				51			13 + 13			15 + 26			12 + 15			6 + 6		
G: GENERAL PURPOSE LABORATORY (GPL) A: ATTACHED RAM D: DETACHED RAM				G+: GPL PLUS SUBSATELLITE J: SHUTTLE SORTIE G+: GPL PLUS ATTACHED RAM														

Table 13. Program Comparison Summary

CHARACTERISTIC	PROGRAM OPTION					
	0-REFERENCE (15-YEAR)	1-BASELINE (10-YEAR)	2-BALANCED (5-YEAR)	3-BALANCED (10-YEAR)	4-APPLICATIONS (10-YEAR)	5-LIMITED FUNDING (5-YEAR)
DISCIPLINES	7	7	7	7	6	6
EXPERIMENT EQUIPMENT GROUPS	51	43	13	26	15	8
SHUTTLE FLIGHTS	123	86	31	55	50	28
ATTACHED EXPERIMENT MODULES	6	7	3	4	2	1
DETACHED EXPERIMENT MODULES	7	4	0	1	0	0

Table 13. Program Comparison Summary (Cont)

CHARACTERISTIC	PROGRAM OPTION					
	0-REFERENCE	6-SORTIE + BALANCED (2)	7-SORTIE + BALANCED (3)	8-SORTIE + APPLICATIONS (4)	9-SORTIE + LIMITED FUND- ING (5)	
DISCIPLINE	7	7	7	7	6	
EXPERIMENT EQUIPMENT GROUPS	SORTIE	0	13	15	12	6
	STATION	51	13	26	15	8
	TOTAL	51	26	41	27	14
SHUTTLE FLIGHTS	SORTIE	0	65	76	73	52
	STATION	123	31	55	50	28
	TOTAL	123	96	131	123	80
ATTACHED EXPERIMENT MODULES	SORTIE	0	8	8	5	4
	STATION	6	3	4	2	1
	TOTAL	6	11	12	7	5
DETACHED EXPERIMENT MODULES (STATION ONLY)	7	0	1	0	0	

PROGRAM OPTIONS COSTS

The program costs for each of the options is shown in Figure 54. The fundamental approach to program options was to reduce program costs and annual funding requirements while still providing significant and early beneficial achievement. This was done primarily by reducing the experiment program to something less than defined in the NASA 1971 Blue Book. The support capability required for full Blue Book implementation is five years of initial (six-man) space station operation plus ten years of growth (12-man) space station operations.

The reference program supplies approximately 107 man-years of crew operating time and involves 51 experiment equipment groups. The cost of developing and operating the support system is \$2.56-billion and the corresponding experiment cost is \$3.96-billion.

Although reductions in support system size (to initial space station only) and operating duration (to five years) resulted in significant cost reduction, a far greater reduction is possible in the experiment system area. By deleting expensive items and reducing the number of attached and free-flying RAM's, the cost can be reduced from \$3.96-billion to \$1.15-billion, and approximately the same balance between science and applications can be maintained as in the reference program. Since science-oriented experiments tend to be more complex and expensive than the applications-oriented ones, a further reduction in equipment groups and a \$370-million cost reduction would result from emphasizing applications objectives instead of maintaining a balanced program.

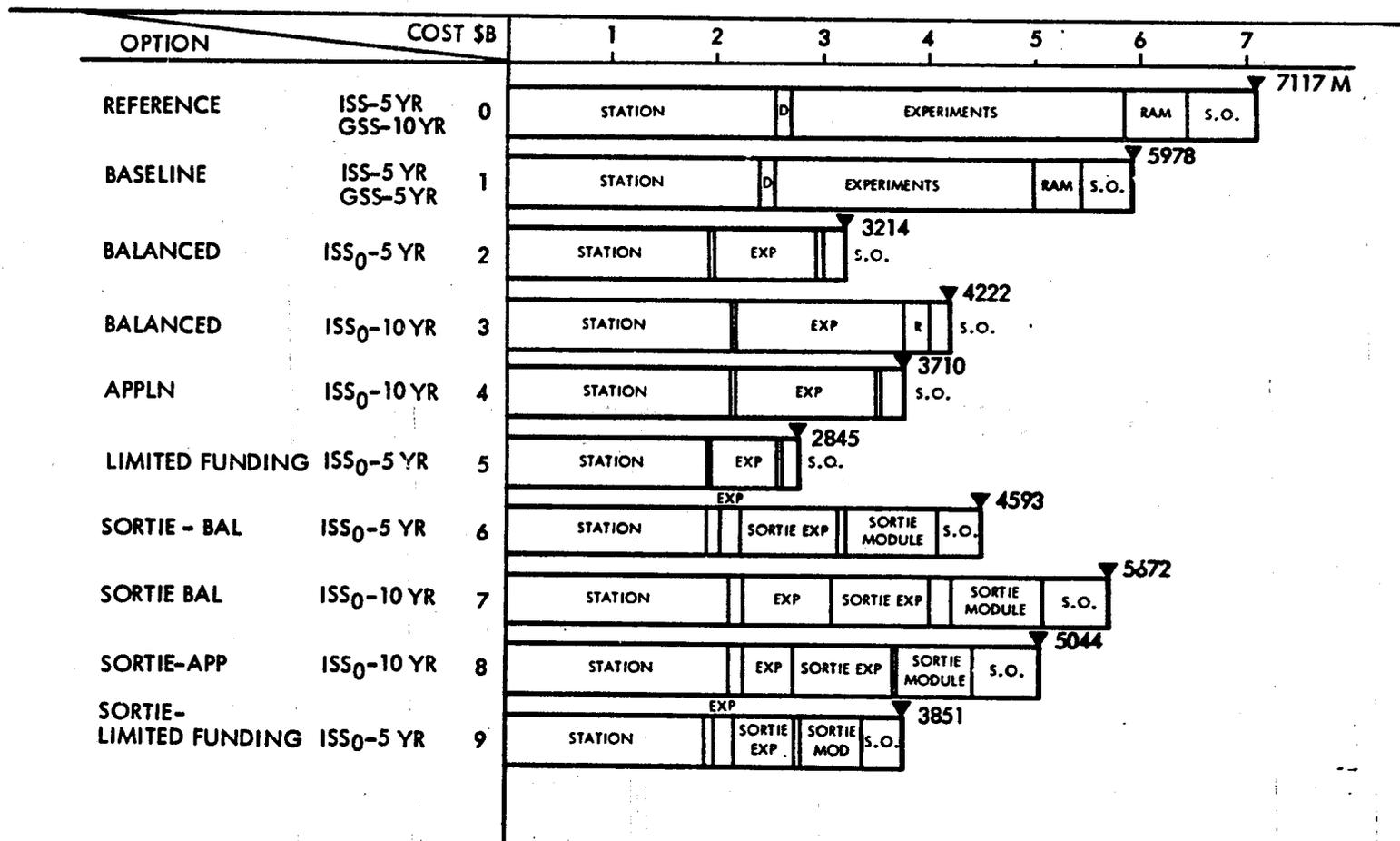


Figure 54. Program Cost Comparisons

OPTION 10

An alternative program option (Option 10) has been examined which requires lower annual funding and produces a significant (approximately \$140-million) reduction in program funding. This option involves extending the ISS development time and reducing the development of sortie experiment carriers to three versions of one basic item. The development period for the space station has been stretched by two years to achieve a lower peak funding requirement and a more relaxed time interval for pursuit of phased development and procurement of the modular space station. The Phase C start date for the station has been held at October 1975 but the IOC date was extended from January 1982 to January 1984. Option 10 mission sequence is shown in Figure 55.

SORTIE LAB	NO	TITLE						
			1979	1980	1981	1982	1983	
A	ES 1 I	METEOROLOGY & THE ATMOSPHERIC SCIENCES		▲	▲	▲	◆	◆
	ES 1 III	AIR & WATER POLLUTION						
	MS 1 I	MATERIALS SCIENCE						
	LS 1 I	BIO MEDICAL RESEARCH						
T	T 1 I	SKY BACKGROUND BRIGHTNESS						
	T 1 II	REAL TIME CONTAMINATION MEASUREMENTS						
	C/N 1 I	TRANSMITTER BREAKDOWN TEST						
	C/N 1 II	MILLIMETER WAVE COMMUNICATION SYSTEM & PROPAGATION DEMONSTRATION			▲	▲	◆	
P	P 1 I	ATMOSPHERIC & MAGNETOSPHERIC SCIENCES				▲	▲	▲
	-	UNCOMMITTED SORTIE MISSIONS		▲		▲	◆	
SHUTTLE SPACE STATION SUPPORT								
TOTAL SHUTTLE UTILIZATION (FLIGHT/YEAR)			1	4	4	6	2	

▲ 7 DAY SORTIE MISSIONS
◆ 30 DAY SORTIE MISSIONS

NO	TITLE	 + 					
		1983	1984	1985	1986	1987	1988
ES 1	EARTH OBSERVATIONS		—	—	—	—	—
MS 1	MATERIALS SCIENCE & MANUFACTURING		—	—	—	—	—
LS 1	MEDICAL RESEARCH		—	—	—	—	—
T 1	CONTAMINATION MEASUREMENTS		—		—		
C/N 1	COMMUNICATION/NAVIGATION		—				
P 1	SPACE PHYSICS RESEARCH				—		
UNCOMMITTED SORTIE MISSIONS (A, T, S)				○	○	○	○
SHUTTLE SPACE STATION SUPPORT			●●●	●●●	●●●	●●●	●●●
TOTAL SHUTTLE UTILIZATION (FLIGHT/YEAR)		2+6+8	5	5	5	5	5

↑ SPACE STATION MODULE DELIVERY
● CREW & CARGO DELIVERY
▲ RAM DELIVERY
○ 7 OR 30 DAY SORTIE MISSIONS

Figure 55. Option 10 Program Characteristics

Prior to station IOC there would be four years of sortie flights. These sortie flights involve the multiple use of three dedicated laboratory modules to provide relatively early and inexpensive experiment operations. The three shuttle sortie laboratories, outfitted for applications, technology, or science would be alternately flown for multiple missions, with various experiments accommodated which require little or no modification to the basic laboratory configuration. The estimated cost profiles for such a program are shown in Figure 56, the peak funding being \$544-million and the total program cost amounting to \$3.486-billion over the 17-year period shown.

APPROACH

- EXTEND ISS DEVELOPMENT TIME 2 YRS
- PROGRAM DURATION: 4 YR SORTIE ONLY + 5 YR CONCURRENT STATION
- THREE SORTIE LABS: APPLICATIONS, TECHNOLOGY, SCIENCE

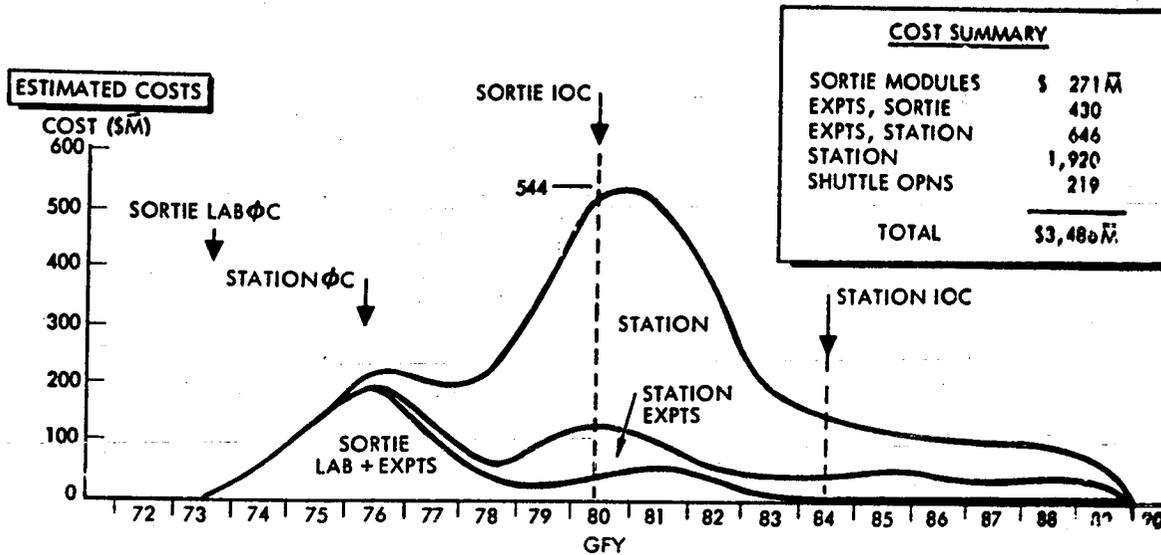


Figure 56. Sortie Laboratory Plus ISS - Typical Program

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General Electric,
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Experiments
Information Management

Hamilton Standard,
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ECLSS preliminary design
ECLSS ventilation

Life Systems, Inc.,
Cleveland, Ohio

ECLSS electrochemical
CO₂ removal design

General Electric,
Binghamton, N. Y.

G&C GMG analysis and preliminary
design

International Telephone
& Telegraph,
Nutley, N. J.

ISS RF communications digital data
bus

System Development Corp.,
Santa Monica, California

ISS DPA configuration

Intermetrics,
Cambridge, Mass.

ISS DPA memory configuration

NR Autonetics,
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ISS DPA configuration

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Sunnyvale, California

EPS solar array (NASA-funded
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Pratt & Whitney Aircraft,
East Hartford, Conn.

EPS fuel cells and electrolysis units

General Electric,
Lynn, Mass.

EPS fuel cells and electrolysis units



Space Division
North American Rockwell

Kollsman Instrument Company,
Syosset, N. Y.

G&C star tracker

Quantic Industries,
San Carlos, Calif.

G&C horizon edge tracker

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